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Design criteria for experienced engineers are presented for harbors, particularly with respect to requirements for military harbors of various types to be used by naval vessels. The contents include general planning criteria, functional layout, data sources, water-area elements of harbors (channels, entrances, turning, berthing, and anchorage basins), and aids to navigation.

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HARBORS

DESIGN MANUAL 26.1

DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
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ABSTRACT

Design criteria for experienced engineers are presented for harbors, particularly with respect to requirements for military harbors of various types to be used by naval vessels. The contents include general planning criteria, functional layout, data sources, water-area elements of harbors (channels, entrances, turning, berthing, and anchorage basins), and aids to navigation.

A

FOREWORD

This design manual is one of a series developed from an evaluation of facilities in the shore establishment, from surveys of the availability of new materials and construction methods, and from selection of the best design practices of the Naval Facilities Engineering Command, other Government agencies, and the private sector. This manual uses, to the maximum extent feasible, national professional society, association, and institute standards in accordance with NAVFACENGCOM policy. Deviations from these criteria should not be made without prior approval of NAVFACENGCOM Headquarters (Code 04).

Design cannot remain static any more than can the naval functions it serves or the technologies it uses. Accordingly, recommendations for improvement are encouraged from within the Navy and from the private sector and should be furnished to NAVFACENGCOM Headquarters (Code 04). As the design manuals are revised, they are being restructured. A chapter or a combination of chapters will be issued as a separate design manual for ready reference to specific criteria.

This publication is certified as an official publication of the Naval Facilities Engineering Command and has been reviewed and approved in accordance with SECNAVINST 5600.16.

W. M. Zobel
Rear Admiral, CEC, U. S. Navy
Commander
Naval Facilities Engineering Command

HARBOR AND COASTAL FACILITIES DESIGN MANUALS

DM Number	Superseded Chapter in Basic DM-26	Title
26.1	1	Harbors
26.2	2	Coastal Protection
26.3	3, 4	Coastal Sedimentation and Dredging
26.4	5	Fixed Moorings
26.5	6	Fleet Moorings
26.6	7	Mooring Design Physical and Empirical Data

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HARBORS

Section 1. INTRODUCTION

1. SCOPE. This manual presents general definitions, spacial and functional considerations of land and water areas, channel depths, aids to navigation, and an overview of administrative permit considerations.

2. CANCELLATION. This manual, NAVFAC DM-26.1, Harbors, cancels and supersedes Chapter 1 of the basic Design Manual 26, Harbor and Coastal Facilities, dated July 1968.

3. RELATED CRITERIA. Certain criteria related to harbors appear elsewhere in the design manual series. See the following sources:

Subject	Source
Cargo Handling Facilities	DM-25.3, DM-38
Berthing and Landing Dimensions	DM-25.1
Operational Structures	DM-25.1, DM-25.5
Navigational Aids	DM-23.2
Protective Structures	DM-26.2
Utilities	DM-25.2, DM-25.6

4. GENERAL FUNCTION. A harbor is a water area bounded by natural features or manmade structures, or a combination of both, which affords safe moorings and protection for vessels during storms. It may serve purely as a refuge, or it may provide accommodations for various water to water or water to land activities, such as resupply, refueling, repairs, or the transfer of cargo and personnel. When areas of a harbor or its entire expanse are used to transfer commercial cargo or passengers, it is referred to as a "port." This definition is commonly used to designate the major commercial cargo-transfer facilities throughout the world. When a harbor, or portions of it, are utilized by the military services for similar functions, it is designated as a "military harbor." Military harbors generally include the landside areas that provide functional support to waterborne naval activity. In these cases, they are variously termed as: naval base, naval station, naval depot, and naval shipyard, depending upon the support activity involved.

5. PURPOSE OF HARBOR CONSTRUCTION. The chief objects in the design and construction of harbors are: (a) to obtain a relatively large area of water, of adequate depth at all stages of the tide, so sited as to provide shelter for ships; and (b) to provide for transfer of cargo and passengers between ships and shore locations and facilities.

6. HARBOR FEATURES. It is seldom feasible to provide all of the desirable characteristics of an ideal harbor at any single harbor location. However, ideal waterside harbor features include:

- shelter from open-sea waves;
- minimum tidal range and moderate currents;
- freedom from troublesome long-wave agitation (seiche);
- freedom from fog and ice;

- access through one or more safe navigational channels under all weather conditions;
- adequate room and depth to maneuver ships within the sheltered area;
- space for an adequate number of fixed moorings;
- shelter from strong winds from all directions;
- minimum maintenance dredging; and
- room for future expansion.

Ideal landside features to accommodate naval ship activities include:

- layout of quays, piers, and wharves to accommodate ships of varying lengths and drafts;
- waterfront structures of dimensions and strength to accommodate weight-handling equipment and cargo-hauling vehicles, including both road and rail;
- utility services at berth;
- covered and uncovered transit storage in the immediate area of the berth, with additional long-term and depot storage at a more remote location where required;
- space for adequate segregation of material and cargo;
- adequate road and rail transportation linkage between the waterside area and inland distribution;
- provisions for the transfer and accommodation of passengers;
- provisions for small craft, shore boats, lighters, and tugs;
- safety from fire hazards;
- minimum general maintenance;
- proximity to labor and material sources;
- proximity to air-transport facilities;
- adaptability of shore installations for alternate uses; and
- room for future expansion.

7. TYPES OF HARBORS. Locations for construction of harbors may range from open coastlines requiring artificial impoundments to natural bays, estuaries, and navigable rivers that need a minimum of manmade structures to afford the necessary storm protection. Within certain limits, harbors may be constructed wherever suitable water depth exists or can be provided and maintained through dredging. The degree of artificial works required to construct a viable harbor will vary with the natural features present at the site. Examples of various siting classifications are illustrated in Figure 1. Characteristics of harbor location types are listed in Table 1.

a. Open Coastlines. Harbors situated on open coastlines usually require a high degree of artificial works to provide shelter. As the coastline becomes more sinuous and offshore islands occur, the degree of natural shelter thus provided reduces the harbor's exposure to wind and waves, and a corresponding decrease in artificial protection is required.

b. Bays, Estuaries, and Navigable Rivers. Total natural protection can occur where the harbor is situated entirely within an enclosed bay or estuary having a narrow opening to the sea. Depending upon the orientation of natural protective features, such harbor sites may require

little or no additional protection. However, some degree of entrance improvement is typically required to ensure safety during storm periods, and as the entrance widens the degree of protection should be increased correspondingly.

c. Hydraulic Impoundments.. Hydraulic impoundments are harbor basins in which vessel mooring depth is constantly maintained behind locks, as opposed to harbors with free-flowing water linkage to the sea or other large bodies of water exposed to storms. Unlike harbors located in bays, estuaries, and rivers, such hydraulic-impoundment harbors are free of tidal fluctuations. Water levels are maintained through pumping or regulating the flow of water through the locks. Although hydraulic impoundments have been constructed worldwide and are economically efficient for commercial port facilities, their constricted access to the sea renders them generally undesirable for military uses.

d. Roadsteads. Where protection is provided solely as a moored-ship refuge, the protected harbor area is referred to as a "roadstead." Roadsteads require a bottom in the protected area suitable for developing anchor holding power. Examples of roadstead moorings are illustrated in Figure 2.

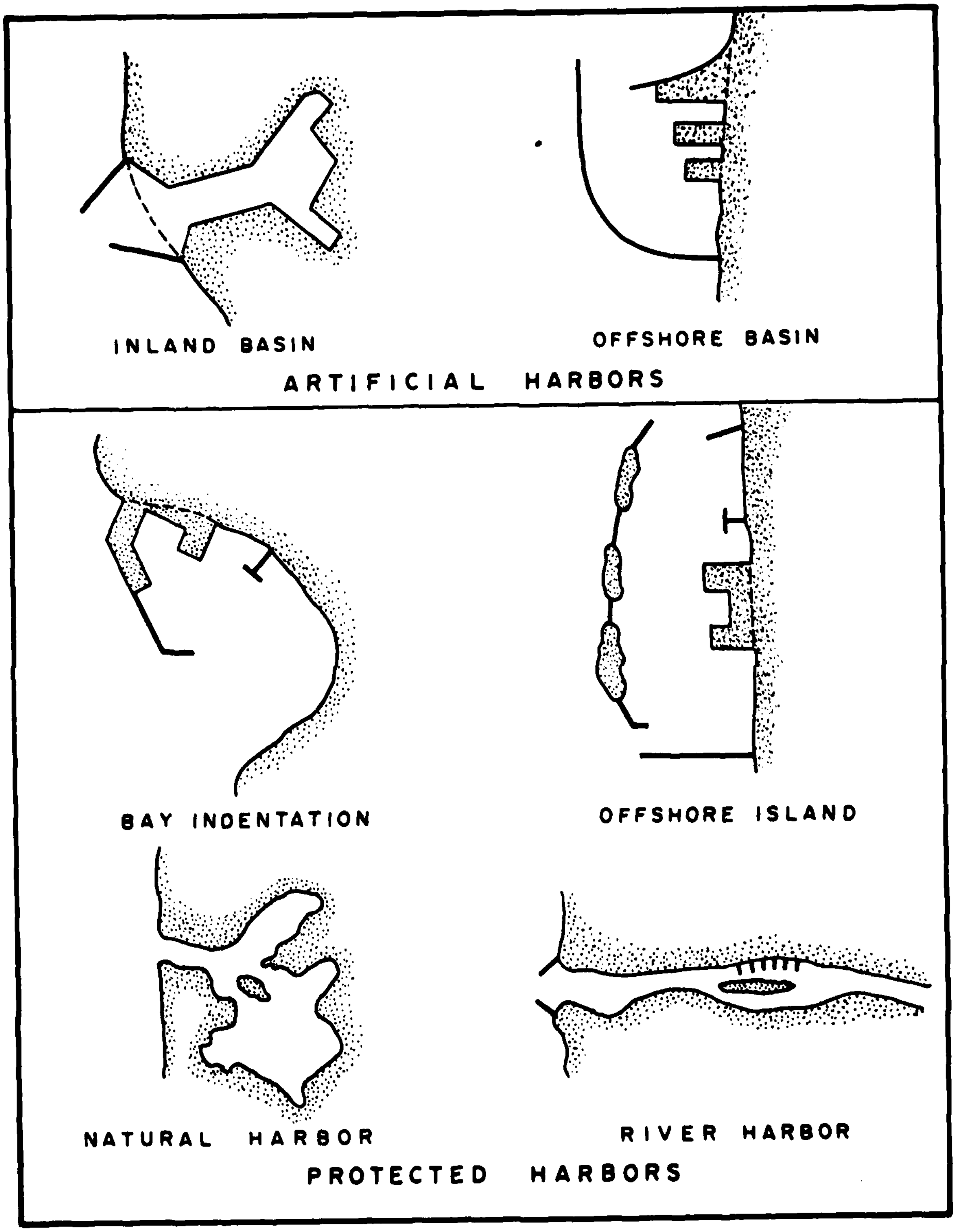


FIGURE 1
Examples of Harbor Siting Classifications

TABLE 1
Characteristics of Harbor Location Types

Type		Characteristics
Artificial--inland basin	Needs:	Low elevation; economical excavation.
	Advantages:	Less breakwater costs; feasibility of expansion.
	Concerns:	Low ground may contain poor soils; potential of flooding and sedimentation from upland sources; distance to offshore navigational water depth; littoral drift; silting.
Artificial--offshore basin	Needs:	Adequate sources for extensive breakwater construction material.
	Advantages:	Normally good foundation conditions can be developed with minimal dredging.
	Concerns:	Construction costs relatively high for harbor size; minimum expansion capability; littoral drift; shoaling.
Protected	Needs:	Shoreline relief features help to reduce storm-wave exposure.
	Advantages:	Less breakwater development cost.
	Concerns:	Can be same as other locations.
Natural	Needs:	Natural ocean access passage of adequate dimensions leading to embayment protected from storm waves.
	Advantages:	Minimal effort required for developing protected water area.
	Concerns:	If not historically used as ship refuge area, ascertain reason (example Lituga Bay, Alaska, which is subject to landslides and massive waves); natural sediment regime should be thoroughly investigated if extensive deepening of natural depths is proposed.
River	Needs:	Historically stable river of adequate natural depths and widths to accommodate proposed vessel sizes.
	Advantages:	Minimal effort required for developing protected water area.
	Concerns:	Currents and water-level fluctuations due to variation in river stages; effects of new works on river's natural alluvial regime require thorough analysis, including effects of salinity changes; extensive basin dredging and channel deepening should be avoided where possible.

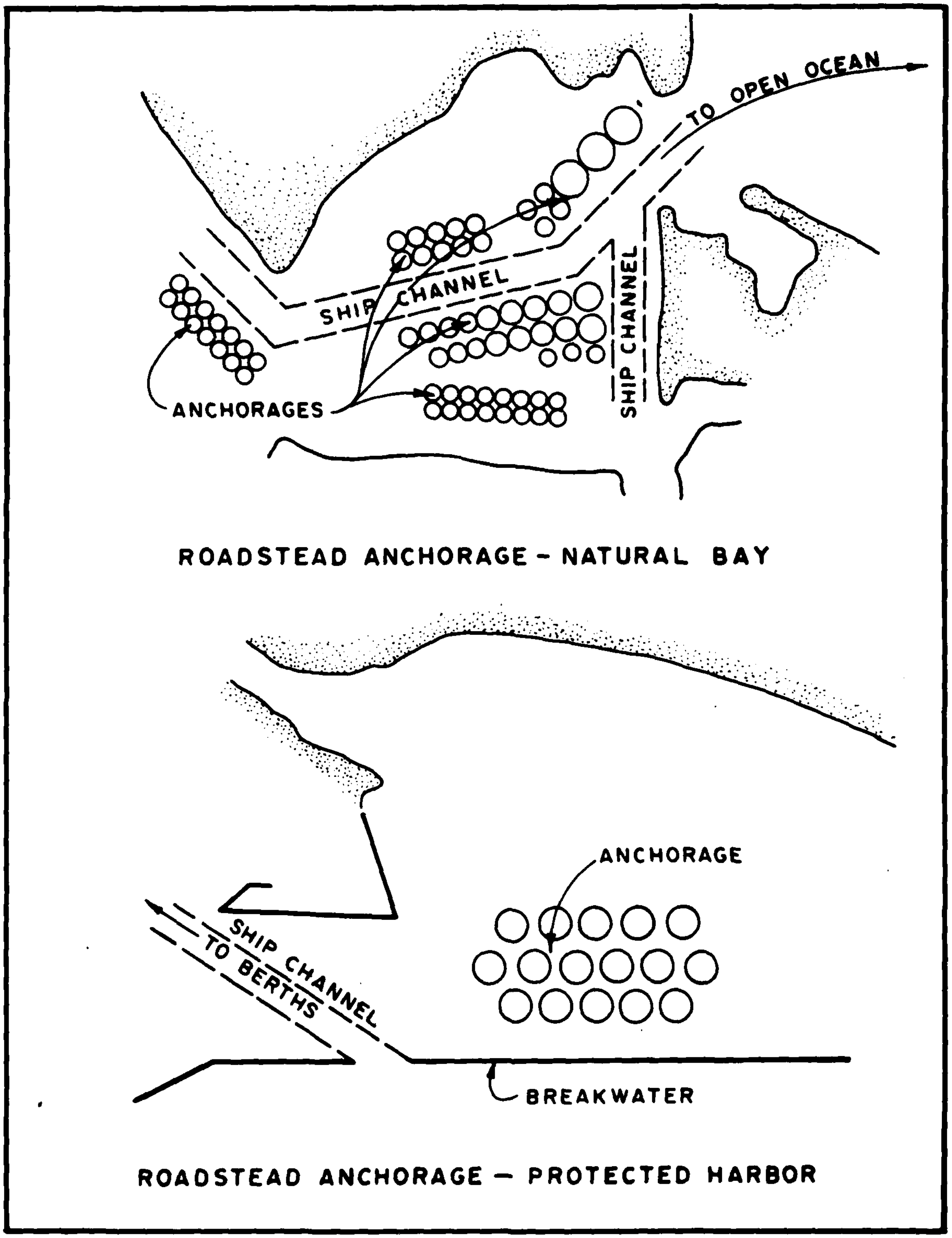


FIGURE 2
Examples of Roadstead Moorings

Section 2. BASIC PLANNING

1. DESIGN DATA. Factors to be considered in general harbor site selection are listed in Table 2. Possible sources of site data information are listed in Table 3.

2. SITE CONSIDERATIONS. Unrestricted choice of a harbor site will rarely lie within the province of the design engineer. The general locality will be determined by preliminary deposition established before the engineer's services are requisitioned. The design engineer will select the specific site within the general locality specified. Site selection is based upon considerations of harbor-use objectives, economics, and, in some military prescribed cases, the expediency of construction. The process of site selection consists of comparing alternative sites and progressively eliminating the less desirable alternatives. Final selection requires the preparation of preliminary layouts and comparative cost and resource estimates.

3. PERMITS.

a. Corps of Engineers.

(1) Jurisdiction. All works located in the waters of the United States and its territories are under the jurisdiction of the U.S. Army Corps of Engineers. This zone is generally located seaward from the mean high-water line. A Corps permit is required for all dredging, filling, construction, or maintenance works. The permit must be approved prior to commencement of work. Therefore, processing of permits should be initiated well in advance of the date work is scheduled to begin because of the lead time required to obtain Corps permits. The Corps' jurisdiction also includes interior wetlands, rivers, and lakes. Questions regarding the extent of the jurisdiction for specific areas inland of the high-tide line should be addressed to the local Corps of Engineers District Office.

(2) Review Procedure. In reviewing permit applications for works in U.S. waters, the Corps of Engineers circulates the application to other Federal and local agencies. In accordance with various executive actions, the Corps of Engineers cannot, at a local level, override the permit objections of the following:

- Department of the Interior--U.S. Fish and Wildlife
- Environmental Protection Agency
- Department of Commerce--Bureau of Commercial Fisheries

In addition to input by Federal agencies, input by State or regional agencies is considered and their objections given strong consideration. To date, most concerns address changes in water quality and loss of marine habitat. In specific cases critical to national defense, regulations and procedures can be modified through the Office of the Secretary of the Navy. However, most naval facility projects are subject to the concerns and regulations of other authorities which have jurisdiction. Specific contact should be made at project inception with the agencies affected. Liaison is particularly important where harbor works involve:

(1) dredging and disposal of dredged materials;
(2) work in or around existing marshes; and
(3) significant reduction of existing intertidal or shallow-water areas.

b. U.S. Coast Guard. All aids to navigation for U.S. waters are prescribed and installed under the jurisdiction of the U.S. Coast Guard (see Section 4). In addition, Coast Guard jurisdiction extends to drawbridges and encompasses construction clearances for new drawbridges, modifications of existing drawbridges, and drawbridge operations.

c. Harbor Control Lines. The Corps of Engineers, through the Secretary of the Army, establishes harbor control lines for all U.S. ports. Control lines include:

(1) bulkhead line--seaward limit of solid-fill structures;
(2) pierhead lines--seaward limit of open waterfront structure; and
(3) channel lines--extent of channel limits usually maintained by the Federal Government.

d. Local Jurisdictions. Most states have federally endorsed coastal development and water quality plans. Many consider the operation and maintenance of existing naval facilities as consistent with and part of their planning documentations. Direct authority over new naval construction works does not presently extend to local State agencies; however, for consistency with local plans, notification of new works is desirable. Notification of concerned local agencies may be through circulation of an environmental impact statement for new works, public notice in the case of operation or maintenance projects, or directly through an exchange of memoranda.

4. WATER-AREA ELEMENTS. Within limits, any site may be made to accommodate the required vessel use. Ideally, the minimum and maximum area requirements must be estimated in order to properly evaluate a proposed location. For military purposes, it is desirable to allow for unrestricted operation of all vessels at all times. However, to design for statistically infrequent low-water conditions, as well as an all-weather navigable entrance at locations exposed to extreme wave climates, is not always practical. Before proceeding with the design, trade-offs based upon the probabilities of occurrences should be discussed with the using agency.

a. Major Water-Area Elements. Figure 3 schematically illustrates the arrangement of major water-area elements associated with a harbor facility. Depending upon siting, a harbor facility may include all of, or portions of, these elements. Functionally, approach- and entrance-channel elements provide the transition between open-sea and protected water environments. The protected interior channel serves as a navigational linkage; in riverine situations, this channel length can become of increasing importance. Turning basins provide area for a ship to maneuver while approaching its final terminus, either alongside berths or in open mooring areas. In some harbors, special water areas are required for vessel electronic and navigation calibration. Sizing of water-area dimensions is related to both capacity and operational requirements.

TABLE 2
Principal Factors in Harbor Siting

Factor	Considerations
External access	1. Vessel access to harbor site contains adequate depths and clearance for safe navigability. 2. Land access to harbor site is or can be reasonably developed to provide required land transportation linkage.
Size and depth	1. Protected water depth and space adequate to accommodate intended vessel traffic in the following areas: (a) entrance and turning basins, (b) mooring areas, and (c) berthing areas. 2. Land areas of sufficient size and elevation to accommodate support needs free from flooding or inundation. 3. Potential for future enlargement or change in harbor use.
Physical and topographic	1. Sheltering from winds and ocean waves; natural sheltering features such as headlands, offshore reefs, and islands will reduce both artificial sheltering requirements (break-waters) and costs. 2. Limited fetch. The protected water area shall not contain segments of sufficient fetch to act as a generating area for waves that would cause difficulties within the harbor. 3. Bottom. Heavy, stiff, or overconsolidated clays furnish the best holding ground for anchors. Sands will provide acceptable holding ground. Sites should be avoided where the bottom consists of extremely hard clays, rocks, or very soft clays. If this is not possible, costly provisions (such as mooring islands) must be made to secure ships. Similiarly, the costs of breakwaters, piers, and shoreside structures will also depend upon the underlying soil conditions. Location of extensive structural systems in areas of deep, soft clays should be avoided. 4. Dredging. Avoid locations involving dredging of large quantities of rock or other hard bottoms. 5. Shoreline relief. Land adjacent to shoreline should gradually slope away from beach. Avoid

TABLE 2
Principal Factors in Harbor Siting (Continued)

Factor	Considerations
Physical and topographic (continued)	locations with pronounced topographic relief (cliffs) adjacent to shoreline.
	6. Upland drainage. Preferably, the upland area should be naturally well-drained. Evaluate occurrence of health hazards due to local conditions.
Hydrographic and hydrological	1. Variations in water level. The range between water-level extremes due to cumulative effects of astronomical and storm tides as well as flood flows in river-affected harbors should be minimized as far as practicable.
	2. Currents. Current velocity should be minimum and, except for localized areas and/or special considerations, should not exceed 4 knots.
	3. Fouling rate. Desirable factor is a low fouling rate and relative freedom from marine borers, hydroids, and other biofouling organisms which can be drawn into the cooling systems of ships.
	4. Water circulation. Water basins should have sufficient natural circulation.
	5. Sedimentation. The effect of the harbor site on natural regimes of coastal and riverine sediment transport and supply must be thoroughly evaluated. It is desirable not to interfere with the natural regime of sediment movements. The effects of harbor development on the sediment system may require maintenance dredging and/or shore-stabilization needs that must be considered as part of the overall development effort.
Meterological	1. Storm. Avoid locations subject to the direct effects of pronounced, severe, and frequent storms.
	2. Fog. Consider local variation in fog intensity and avoid the more severe sites where practicable.
	3. Ice. Avoid locations which might be ice-locked for several months a year.
Other	1. Availability of construction material. In particular, rock for breakwater and jetty construction.
	2. Fresh water availability. In particular, water for potable water supply.

TABLE 3
Informational Sources for Harbor Site Selections

Data Required	Sources
Underwater bathymetry	National Ocean Survey (NOS): U.S. Naval Oceanographic Office; Defense Mapping Agency; Dept. of the Army Corps of Engineers; Local Government Public Works; and/or Hydrographic Survey Offices. Where such is not available, survey is required.
Upland topography	U.S. Geological Survey; Defense Mapping Agency; local Government Public Works mapping offices.
Subsoil characteristics	Borings, probings, or seismic survey. Use diver for preliminary reconnaissance.
Astronomical tides	National Ocean Survey or U.S. Naval Oceanographic Office. Observation at site.
Storm surge/tsunamis	Site history. In some areas probability forecasts have been prepared by Dept. of Army Corps of Engineers and/or Dept. of Housing and Urban Development--Flood Insurance Agency. Review of available tide records (marigrams) comparing predicted astronomical tide to measured water levels during storm or tsunami occurrences can provide some insight.
Seiche	Historic experience in general area including marigram inspection can provide some indication of potential activity. Long-term observations at site are desirable if potential exists.
Currents	U.S. Naval Oceanographic Office, National Ocean Survey, Pilot Manuals, U.S. Geological Survey (Rivers).
Meteorological characteristics	Weather Bureau (NOAA); USN Fleet Weather Center.
Waves	NOAA; National Climatic Center; DM-26.2; USN Fleet Weather Center; Dept. of Army Corps of Engineers; local measurements and hindcasts.
Sedimentation/erosion	Dept. of Army Corps of Engineers; U.S. Geological Survey; analysis of shoreline and hydrographic changes in comparison of successive surveys from initial to present conditions.
Fouling conditions	Observations at site; consultation with local residents and authorities. See NAVFAC MO-310.

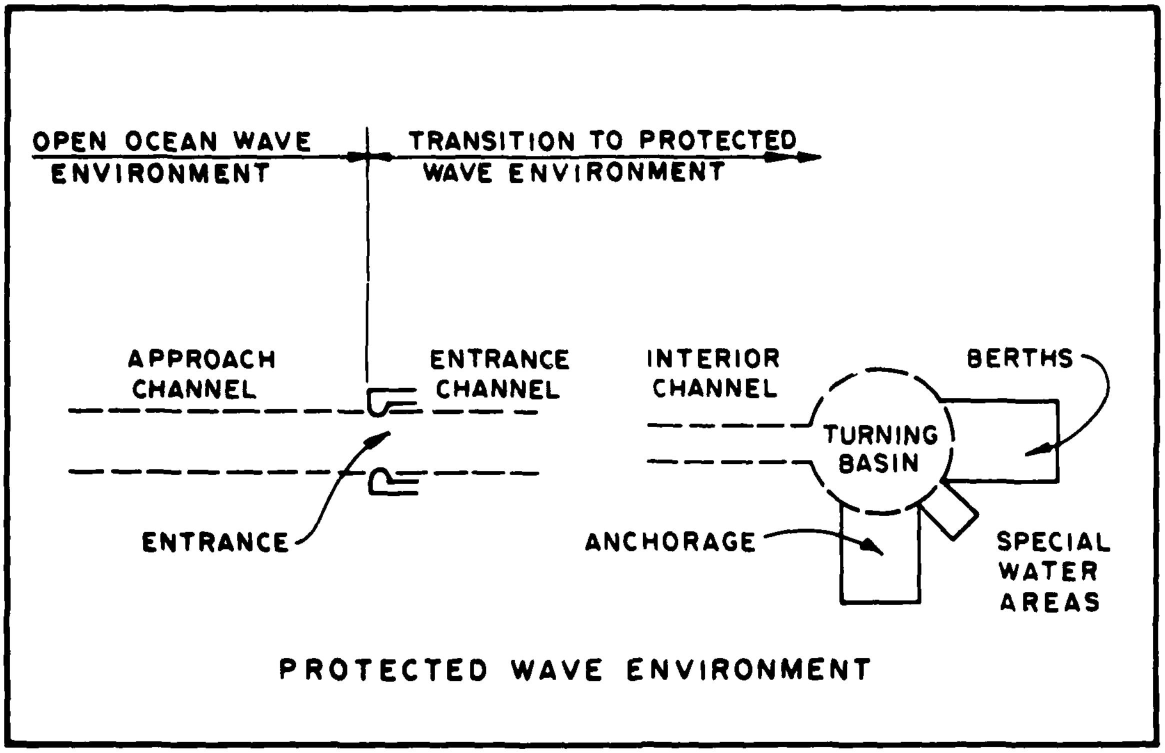


FIGURE 3
Water-Area Elements

b. Capacity. Ascertain the approximate anticipated capacity requirement from the using agency in terms of numbers, types, and sizes of vessels expected to simultaneously anchor within the harbor limits. Also estimate the number of these vessels which must be simultaneously accommodated at pier or wharf berths. Determine the needs for special water areas for ship calibration.

c. Operation. Proposed vessel-handling methods and navigational minimums need to be defined. Included in this assessment is the use of pilots and tugs for ship handling and berthing. Tolerances for ship movement restrictions in cases of extreme tide or weather conditions need to be defined.

d. Dimensioning. Dimensioning of harbor water-area elements is discussed in Section 3. These guidelines provide desired spatial and water-depth values. Alternative evaluations may be made through comparison using existing operating naval facilities. However, caution should be exercised in making such operational comparisons in that, to do so, the wind, wave, and current environments must also be similar.

(1) Water Areas. The water-area elements of harbors schematized in Figure 2 are composed of channels for vessel transit and basins for vessel maneuvering, berthing, and anchorage.

(2) Channels. General channel classifications and elements are shown on Figure 4.

e. Economics. Economic considerations must be weighed against depth requirements. In harbors where tidal range is very large and, particularly, where an entrance channel is long, consider the possibility of restricting the entrance of the largest draft ships using the harbor to the higher tidal stages. Where hard bottoms prevail and excavation costs are high, consider the exclusion of certain classes of deep-draft vessels, with provision of lighter service between deep-water anchorage and docks.

5. WAVE PROTECTION. The harbor configuration should provide adequate wave shelter in the form of interior basins for mooring and berthing of ships. Limiting values of wave heights in interior basins should include consideration of vessel-to-wavelength ratios. For large naval vessels and non-resonance storm-wave conditions, a preliminary design criteria using a 4-foot limiting wave height may be applied. In cases of small craft, the limiting wave height should be 2 feet. Details of storm-wave penetration analysis are addressed in DM-26.2. Long-wave agitation of harbor basins is noted in Section 2.8, SEICHE, of this manual.

6. DEPTH REQUIREMENTS. Generally, harbor-area depths vary. Certain areas are set aside for the use of small craft and other areas for the use of larger ships. Depth requirements for channels differ from those at anchorages and berths. No matter which area is under consideration, provision of adequate depth at all anticipated water levels is essential.

a. Naval Vessel Characteristics. A tabulation of some of the characteristics of auxiliary and combatant vessels as well as service craft is given in Table 4. Where the harbor design requires critical clearances for a particular vessel type or condition, specific verification by NAVSEA Ship Logistic Manager is required.

b. Preliminary Design Depth. Table 4 lists suggested design depths for preliminary design purposes. The depths have been developed to incorporate certain generalized approximations of overdepth allowances for static eccentricities, wave motion, and bottom-clearance allowances. In cases where either unique siting or vessel conditions appear critical in harbor-depth selection, a more detailed analysis of each of the previously described factors is required. Knowing the vessel type, the designer should obtain the maximum navigational draft from Table 2 of DM-26.6 to determine whether or not the proposed depth is great enough to avoid interference with the vessel's hull and any special electronic apparatus that might be attached. This is applicable primarily to destroyers, cruisers, and frigates.

(1) Anchorage and Berthing Areas. For a specific vessel, the depth requirements at anchorage and berthing areas are identical. The required depth for an undamaged vessel is estimated by adding 4 feet to the maximum navigational draft. (See Table 4.) Berthing depths for floating drydocks are listed in Table 5. These estimates are based upon the maximum submerged draft plus 2 feet.

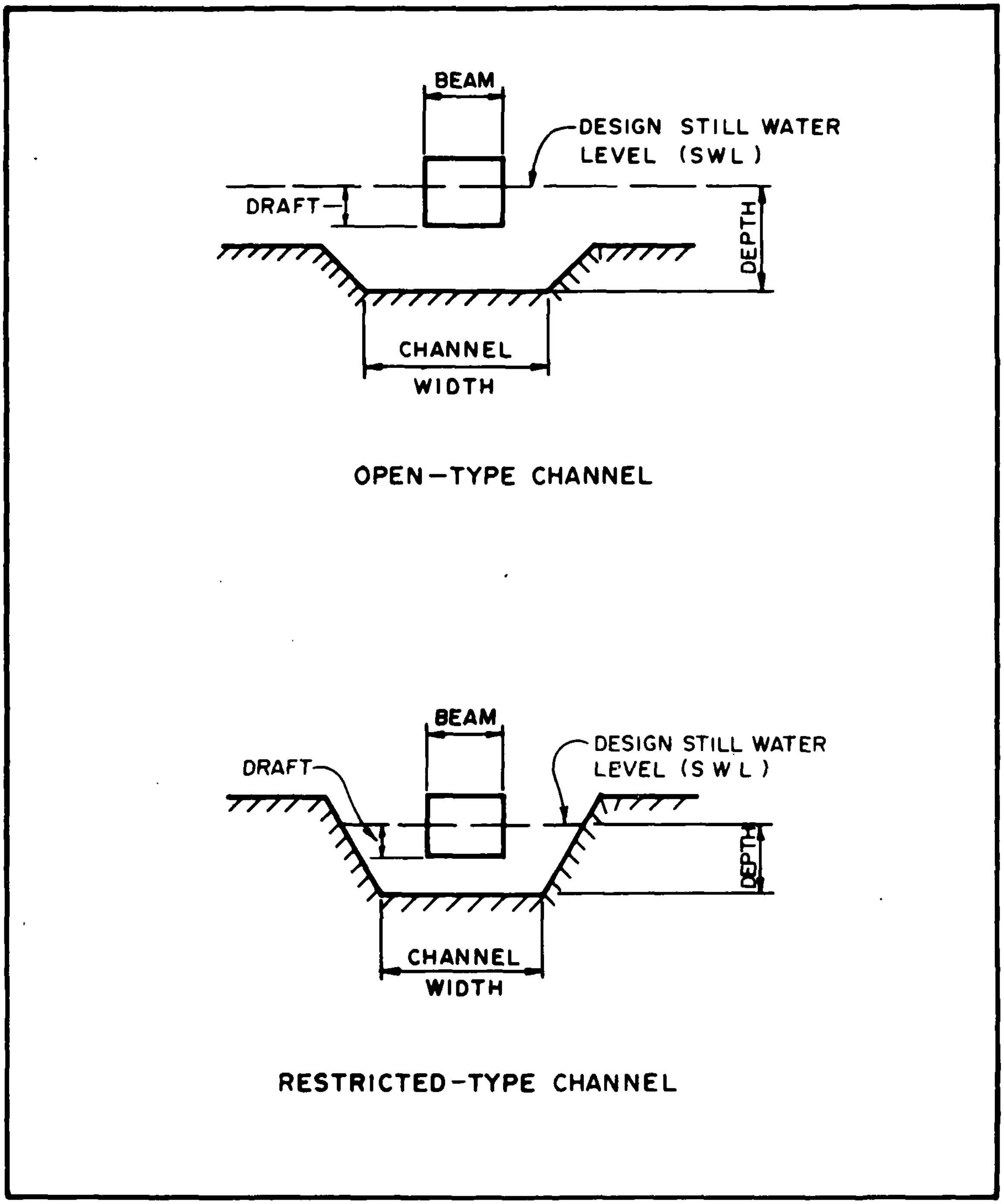


FIGURE 4
Channel Types

TABLE 4
Vessel Characteristics and Berthing Depths

Type	Designation	Characteristics (ft) L.O.A. (l_v)	Breadth Extreme	Breadth @Waterline	Max. Nav. Draft	Undamaged Berthing Depth
Aircraft carrier Nimitz class	CVN 68	1,092.0	257.0	134.0	41.0	45.0
Fast combat support ship	AOE 1	796.0	107.0	107.0	41.0	45.0
Aircraft carrier	CV 66	1,048.0	252.0	130.0	38.0	42.0
Replenishment oiler	AOR 1	659.0	96.0	96.0	36.5	40.5
Tanker	AOT 182	672.0	89.0	89.0	36.2	40.2
Submarine Ohio class	SSBN 726	560.0	....	....	35.9	39.9
Guided missile cruiser	CGN 38	586.0	63.0	61.0	32.6	36.6
Submarine Lafayette class	SSBN 616	421.0	33.0	25.0	32.0	36.0
Guided missile destroyer (Aegis).........	DDG 47	568.0	55.0	55.0	31.6	35.6
Guided missile cruiser	CGN 36	596.0	61.0	60.0	31.0	35.0
Submarine Los Angeles class	SSN 688	361.0	33.0	29.0	30.5	34.5
Guided missile cruiser	CG 26	547.0	55.0	54.0	30.5	34.5
Destroyer	DD 963	564.0	55.0	55.0	30.0	34.0
Amphibious command ship	LCC 19	620.0	108.0	82.0	30.0	34.0
Destroyer tender	AD 37	645.0	85.0	85.0	30.0	34.0
Submarine tender	AS 36	644.0	85.0	85.0	30.0	34.0
Submarine sturgeon class	SSN 637	289.0	32.0	25.0	29.0	33.0
Amphibious cargo ship	LKA 113	576.0	82.0	82.0	28.0	32.0
Amphibious transport	LPA 248	564.0	76.0	76.0	28.0	32.0
Combat store ship	AFS 1	581.0	79.0	79.0	28.0	32.0
Guided missile destroyer	DDG 37	513.0	53.0	52.0	27.0	31.0
Frigate	FF 1052	438.0	47.0	47.0	26.5	30.5
Amphibious assault ship	LHA 1	820.0	118.0	106.0	26.0	30.0
Repair ship	AR 5	530.0	73.0	73.0	26.0	30.0
Guided missile destroyer	DDG 2	437.0	47.0	46.0	24.0	28.0
Amphibious transport dock	LPD 4	570.0	105.0	84.0	23.0	27.0
Dock landing ship	LSD 36	553.0	84.0	84.0	20.0	24.0
Tank landing ship	LST 1179	565.0	70.0	70.0	20.0	24.0
Destroyer	DD 718	319.0	41.0	40.0	19.0	23.0
Submarine	SS 567	293.0	27.0	24.0	17.3	21.3
Salvage ship	ARS 38	214.0	43.0	43.0	15.1	19.1
Minesweeper	MSO 427	173.0	35.0	35.0	14.0	18.0

Notes:

1. Berthing depths are usually measured from extreme low water (ELW).
2. Berthing depths for undamaged vessels are minimum values obtained by adding 4 feet to the maximum navigational draft of the vessel. In case of excessive silting (1 foot per year or over), more than 4 feet should be added.
3. To obtain information concerning berthing depths for damaged vessels, the reader is referred to NAVSEA Ship Logistic Managers for the particular vessel.
4. For more complete listing of naval vessel characteristics, see Table 2, DM-26.6.
5. To obtain optimum berthing depth for CVN, AOE, and CV vessels, refer to Underkeel Clearance Study, Hydro Research Science, Inc., Project Report No. 092-81, 31 March 1981.

TABLE 5
Berthing Depths Required for Active Floating Drydocks[1]

Class of Drydock	Number of Sections Per Dock	Length[2] (ft)	Beam (ft)	Required Berthing Depth[3] (ft)
AFDB-1	5	412	256	84
AFDB-2	10	827	256	84
AFDB-3	9	743	256	84
AFDB-4,5	7	725	240	72.5
AFDB-7	4	413	240	72.5
AFDL-1,2,6,8 to 12, 15,16,19 to 21, 23,25,29	1	200	64	31
AFDL-7,22,23,33	1	288	64	34
AFDL-37,38,40,41, 44,45	1	389	84	40
AFDL-47	1	448	97	45
AFDL-48	1	400	96	53
AFDM-1,2	3	544	116	53
AFDM-3,5 to 10	3	552	124	57
ARD-5 to 8	1	414	71	38
ARD-12,24,30,32	1	414	81	38
ARDM-1,2	1	414	81	38
ARDM-3	1	438	81	49
ARDM-4	1	432	96	61
YFD-7	3	552	124	55
YFD-8	6	587	133	54
YFD-23	6	472	114	50
YFD-54	1	352	90	41
YFD-68 to 71	3	528	118	52
YFD-83	1	200	64	31

Note: The displacement of floating drydocks and their maximum draft when submerged may be obtained from Table 3, DM-26.6.

[1] Berthing depths are usually measured from extreme low water (ELW).
[2] Without outriggers.
[3] Berthing depth required is equal to maximum draft of floating drydocks in submerged condition plus 2 feet. In case of excessive silting (1 foot per year or over), more than 2 feet should be added.

(2) Channels. For fully operational channels protected from direct storm-wave attack, the desirable ratio of channel depth to navigational draft of the largest vessel should be 1.3 for vessel speeds of less than 7 knots, and 1.5 for vessel speeds in excess of 7 to 8 knots. At these ratios, the bottom effects on vessel handling become negligible. In many instances, these desired criteria are not obtainable. For general design minimums used in preliminary harbor planning, but subject to subsequent detailed analysis, use the following approximations:

Vessel Type	Channel Depth (ft)
CV & AOE	45
CG	36
Destroyers, submarines, and auxiliary ships	Maximum navigational draft plus 5
Small craft	12 to 15

c. Detail Depth Design. The depth of the channel is determined by adding the estimated maximum vessel draft and bottom clearance relative to a design still water level (SWL). The maximum vessel draft is determined through consideration of the various factors illustrated in Figure 5.

(1) Static Draft. The extreme draft of a vessel at rest in still water equals the distance from the water surface to its lowest underwater extremity. The value for the maximum loaded draft of an undamaged vessel must be adjusted to account for list, trim, and water density changes. Values with these adjustments for critical situations need verification from the using component. From preliminary estimates: list is 3 degrees, trim 4 inches per 100 feet of vessel length stern down, and salt water-to-fresh water transition sinkage equals 2-1/2 percent draft increase.

(2) Wave Motion. Where a vessel is in a water area subject to wave action, vertical motions will increase the extreme draft relative to the still water level. Rotational motions of pitch and roll, as well as vertical displacement through heaving motion, will occur. The motion of the ship subjected to steep waves requires dynamic analysis involving the physical property of the ship modeled in the sea condition. Under certain critical ratios of vessel length to relative wavelength, added vertical sinkage of the vessel can be appreciably greater than the water-level displacement at the wave trough. In general, these critical ratios are believed to be in the 0.3 to 0.6 range. This situation is normally critical where the unprotected harbor-entrance approach is in shoaling water. A recent harbor site selection at a particularly stormy site suggests that an overdepth in the approach and entrance channels on the order of 35 percent of draft is required. In semiprotected water areas (such as wherein a ship is subjected to swell but not to local seas), the increased displacement of the vessel due to pitch and heave can be determined by placing two points of the vessel on a trochoidal wave surface at two-thirds the vessel waterline-length normal to the wave crests, as shown in Figure 6. Examples of semiprotected water areas are shown in Figure 7.

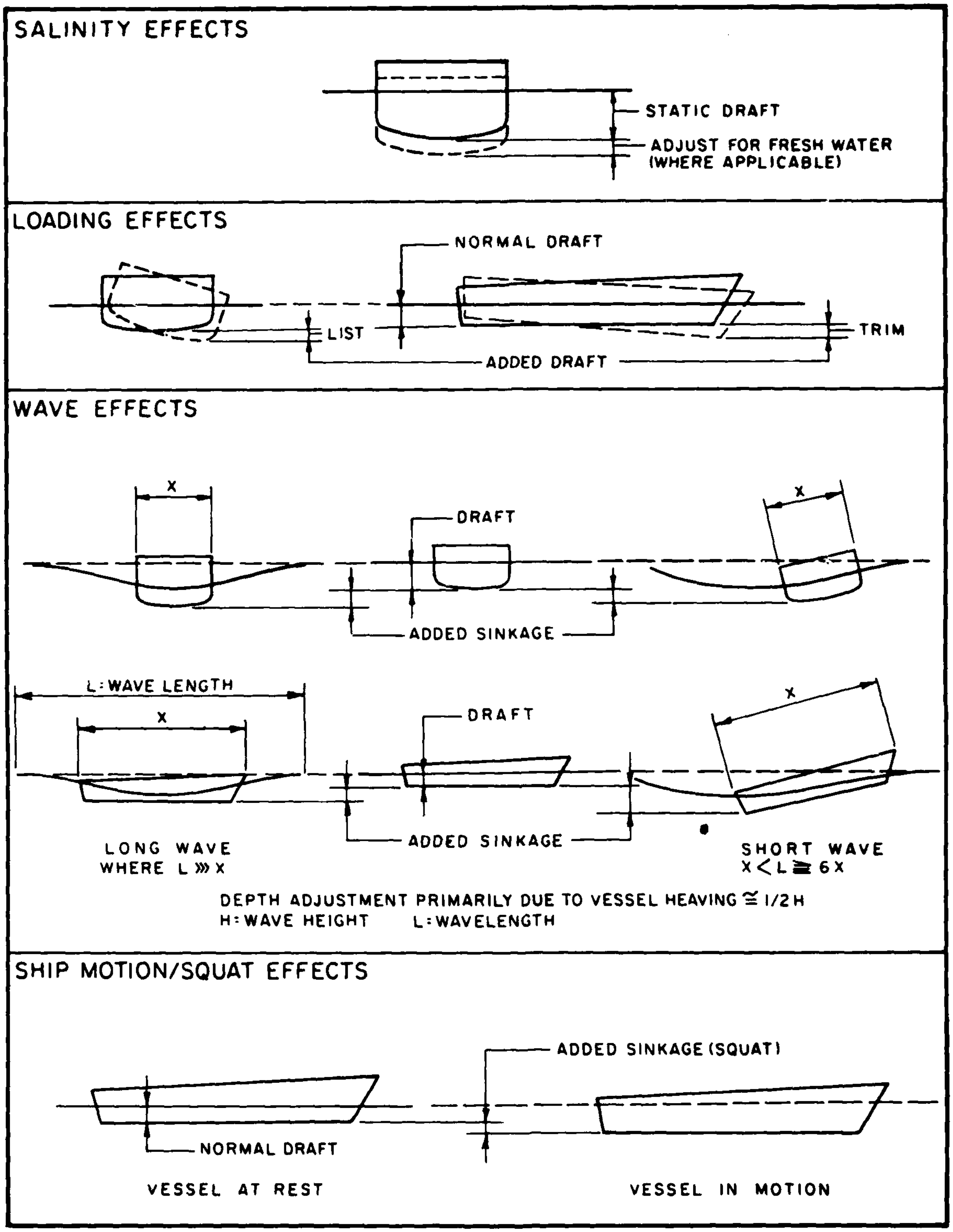


FIGURE 5
Factors Affecting Maximum Vessel Draft

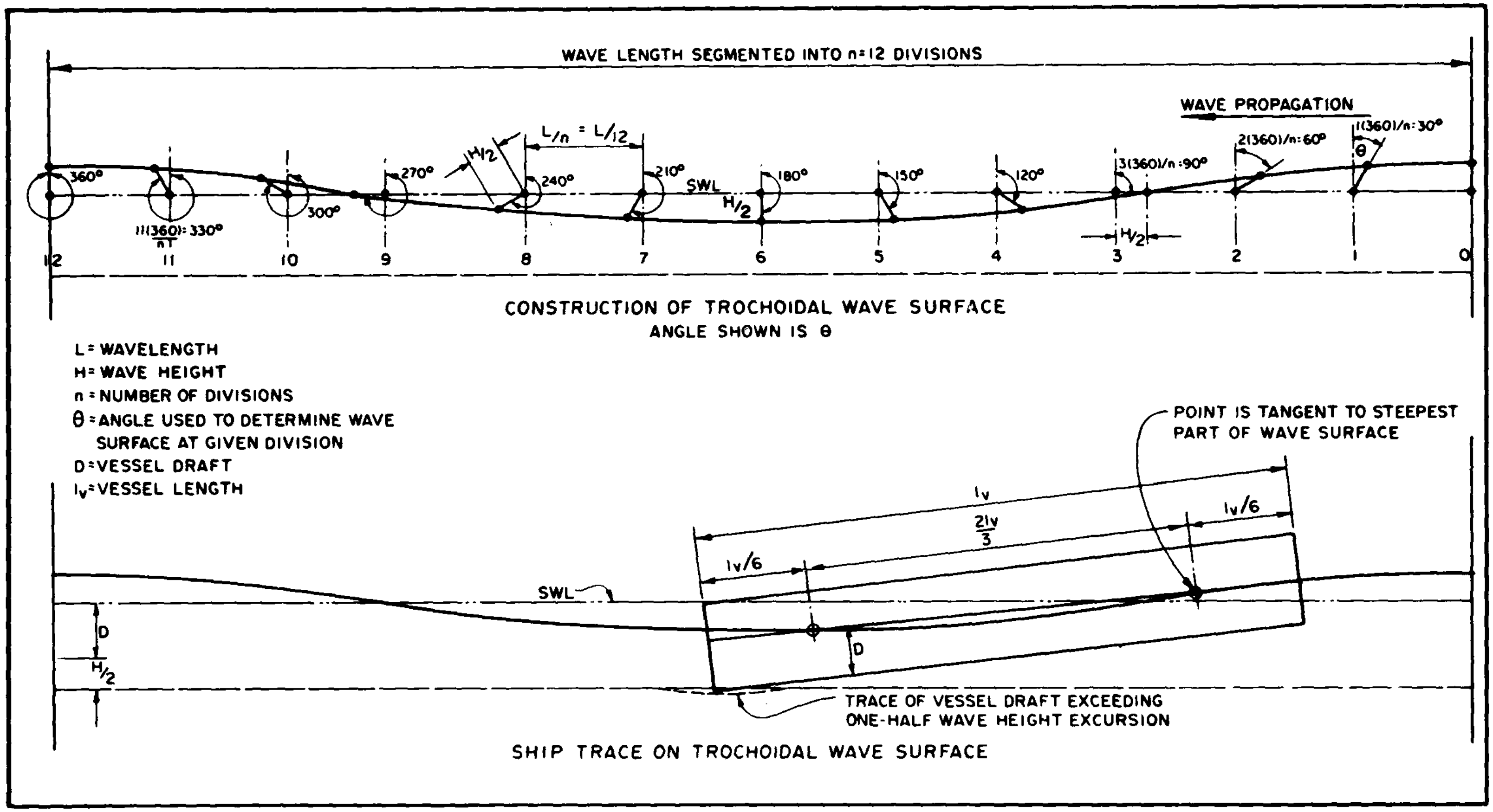


FIGURE 6
Increase in Vertical Sinkage Due to Wave Action

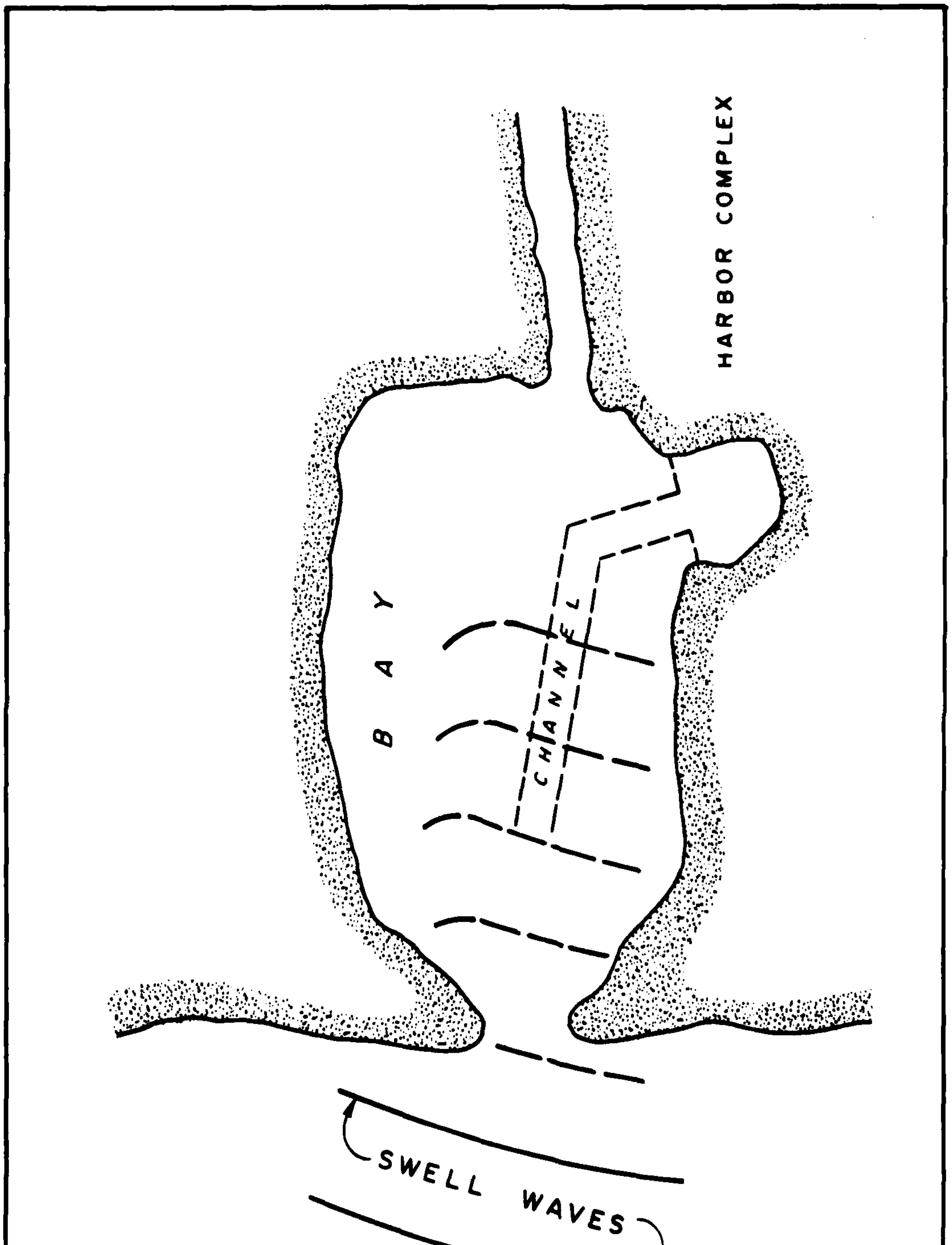
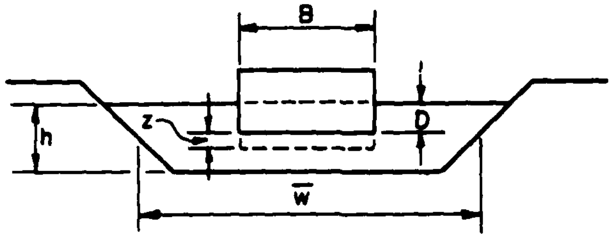


FIGURE 7
Example of Semiprotected Water Area

(3) Squat. When a vessel is underway in shallow water or in a restricted channel, the water surface near the quarter point of the vessel drops below the normal level and the vessel tends to settle or squat in the depression. (See Figure 8). The amount of squat depends upon:

(1) the speed of the vessel through the water;
(2) the distance between the keel and the bottom;
(3) the trim of the vessel;
(4) the cross-sectional area of the channel;
(5) the presence of other vessels in the channel passing or overtaking the subject vessel; and
(6) the location of the vessel relative to the channel's centerline.



WHERE:
- z = depth of squat, in feet
- h = channel depth, in feet
- $\bar{w}$ = average channel width, in feet
- A = underwater *midship cross section*, in square feet = DB
- D = vessel draft, in feet
- B = vessel beam, in feet
- V = vessel speed through water, in feet per second
- V_L = theoretical limiting vessel speed, in feet per second
- g = gravitational acceleration (32.2 feet per second^2)
- S = ratio of underwater midship cross section to the channel cross section = $A/\bar{w}\,h$
- F = Froude number = $V_L/\sqrt{gh}$

FIGURE 8
Factors Affecting Squat

The following procedure is recommended for preliminary estimation of squat:

(1) Compute $S = A/\bar{w}h$.
(2) Using Figure 9, obtain F; compute V_L using $F = V_L/\sqrt{gh}$.
(3) Compute V/V_L and h/D; obtain z/h using Figure 10.
(4) Multiply by h to obtain z_{max}, valid for $\bar{w}/B = 6$.
(5) For other values of $\bar{w}/B$, find $\Delta z/z_{max}$ from Figure 11; determine correction factor Δz.
(6) Compute z using $z = z_{max} + \Delta z$.

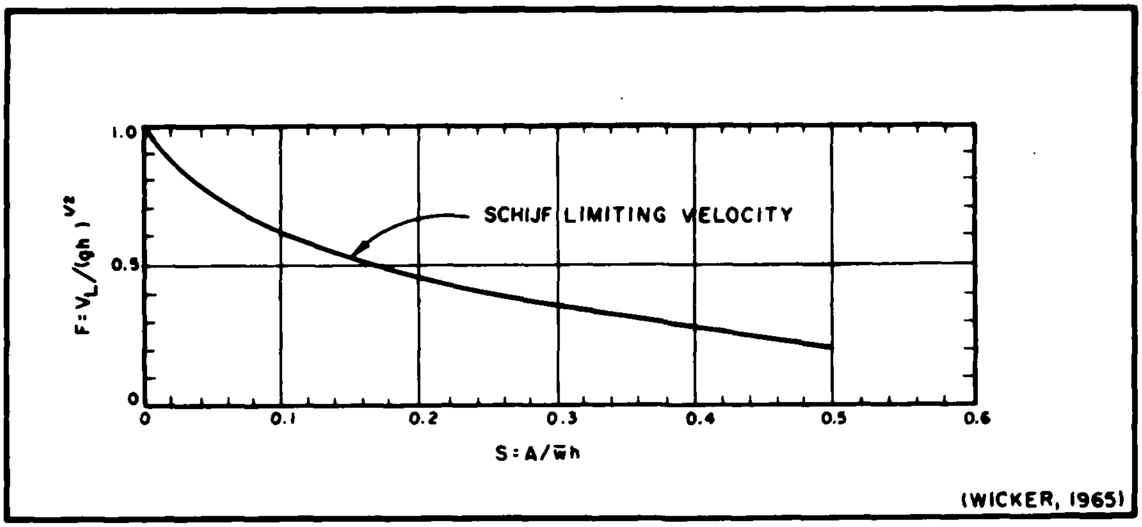


FIGURE 9
Sogreah Laboratory Squat Curve

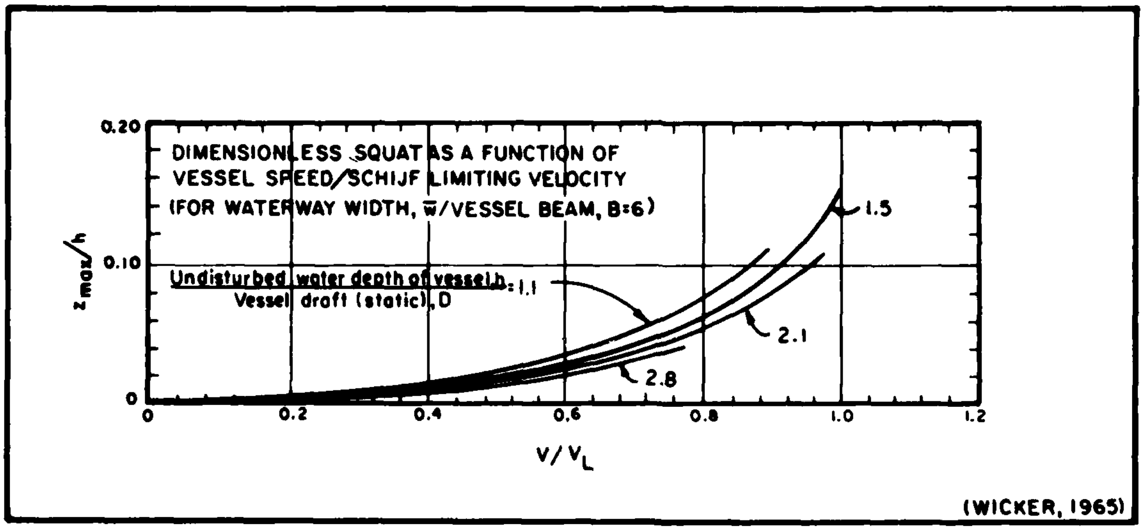


FIGURE 10
Sogreah Laboratory Squat Curves

The amount of squat will increase when vessels travel near one side of the channel. This effect has been shown in a model test for a 32-foot-draft by 113-foot-beam vessel in a 500-foot-wide by 45-foot-deep channel with 1-on-1 side slopes. The results for this test are given in Figure 12. The figure shows that the additional squat due to a vessel traveling near the side of a channel is small for slower velocities. For higher velocities, additional squat due to a vessel traveling near the side of the channel may be 50 percent greater than if the vessel were in the center of the channel.

Squat will also be increased if there are two or more vessels passing one another side by side. A vessel will normally travel near the side of a channel when it is passing alongside another vessel. In this case, the effective cross-sectional area of the channel will be reduced by the cross-sectional area of the vessel being passed. The total squat for a vessel can be approximated by first calculating the centerline squat with the reduced effective cross-sectional area of the channel. To this centerline squat is added the additional squat resulting from the vessel being off the centerline of the channel.

Where the results of this approximation appear critical to sustained operation or to project costs, additional investigations using appropriate hydraulic model studies should be made.

EXAMPLE PROBLEM 1

Given: An AOT tanker with draft of 36.5 feet and beam of 89 feet enters the San Diego Harbor entrance channel at a speed of 10 knots relative to the channel velocity. The San Diego Harbor entrance channel has a width of 800 feet and a depth of 41 feet. The ship is in the center of the channel and is the only ship in the channel.

Find: The squat in feet.

Solution:

h = 41 feet
$\bar{w}$ = 800 feet
D = 36.5 feet
B = 89 feet
V = 10 knots

(1) $S = A/\bar{w}h = DB/\bar{w}h = (36.5)(89)/(800)(41) = 0.099$

(2) From Figure 9 for $S = 0.099$:

$F = V_L/\sqrt{gh} = 0.63$

$V_L = (0.63)\left[(32.2)(41)\right]^{1/2} = 22.89$ feet per second

EXAMPLE PROBLEM 1 (Continued)

(3) $V = 10$ knots

Conversion: 1 knot = 1.688 feet per second

$V = (10)(1.688) = 16.89$ ft/ second

$V/V_L = 16.89/22.89 = 0.738$

$h/D = 41/36.5 = 1.123$

From Figure 10 for $V/V_L = 0.738$ and $h/D = 1.123$:

$z_{max}/h \doteq 0.062$

(4) $z_{max} = 0.062\ h$

$z_{max} = (0.062)(41)$

$z_{max} = 2.542$ for $\bar{w}/B = 6$

(5) $\bar{w}/B = 800/89 = 8.99$

From Figure 11 for $\bar{w}/B = 8.99$ and $h/D = 1.123$:

$\Delta z/z_{max} = +7.0$ percent

$\Delta z = (7.0 \text{ percent})(z_{max})$

$\Delta z = +(7.0/100)(2.542)$

$\Delta z = +0.178$

$\text{Squat} = z = z_{max} + \Delta z$

$z = 2.542 + 0.178 = 2.720$ feet

Squat = 2.72 feet

(4) Bottom-Clearance Allowance. Factors in addition to those presented above that must be considered in determining the clearance between the maximum vessel draft and the bottom are: vessel operation, type of bottom material, and a factor of safety.

(a) Vessel operation. Vessel handling and maneuverability become sluggish at low bottom clearances.

(b) Bottom material. Soft bottom material can be displaced and shoaled by passing vessel propeller action. Hard bottoms with sharp outcroppings can cause severe damage to vessels upon grounding. In active sedimentation areas, bottom shoals can occur during relatively short

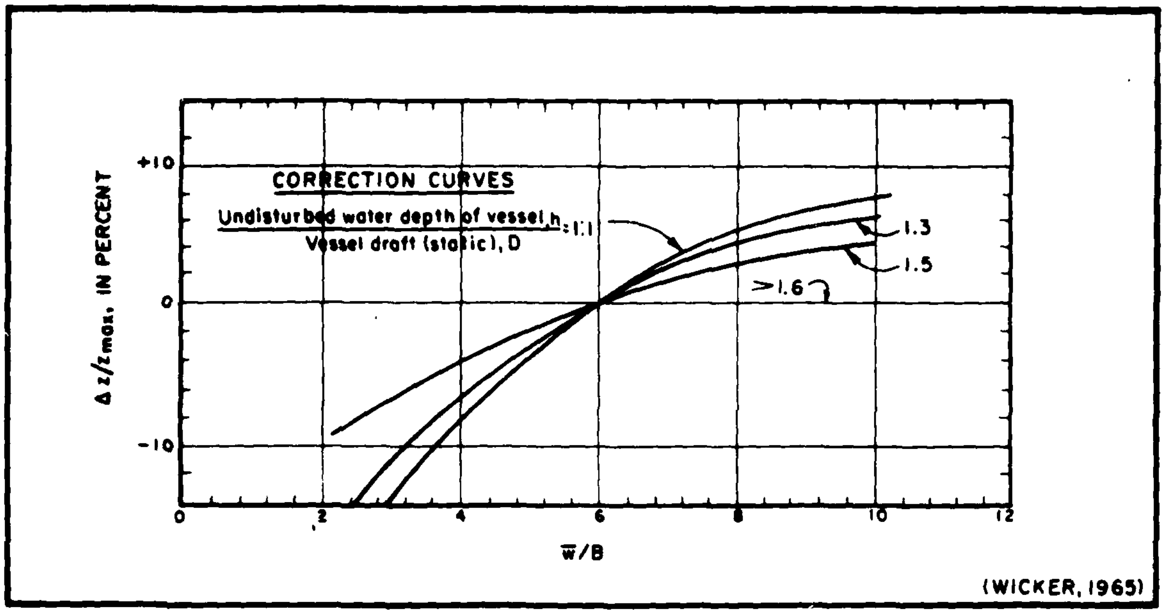


FIGURE 11
Sogreah Laboratory Squat Curves

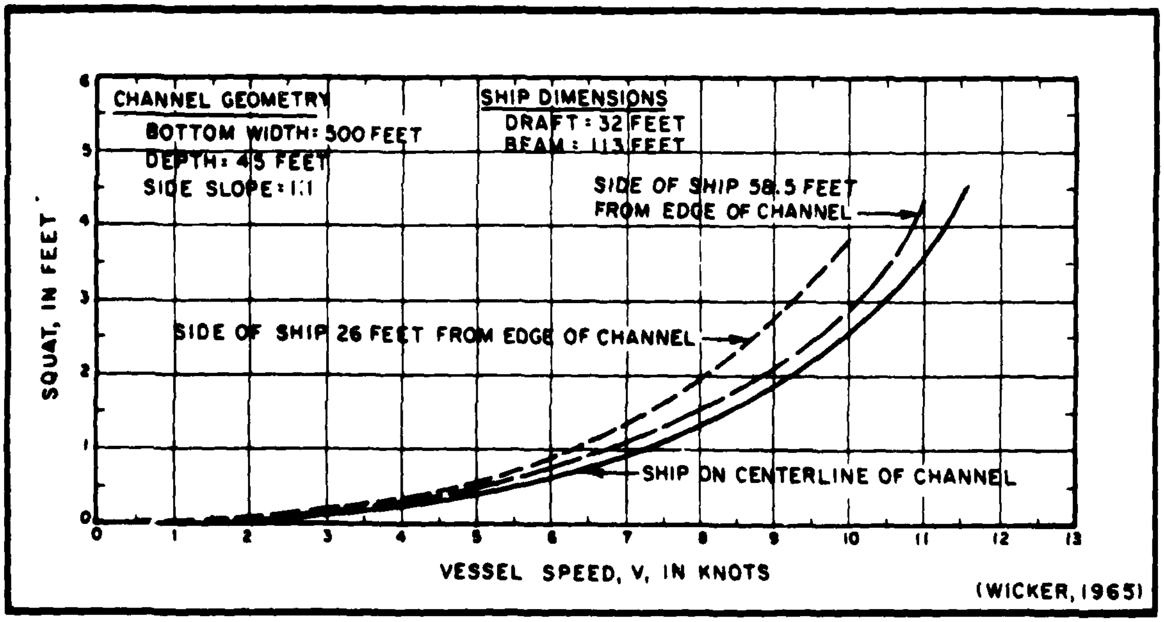


FIGURE 12
Effect of Ship's Location in Channel on Squat

periods of storm activities.

(c) Factor of safety. A clearance of 2 feet between maximum vessel draft and the bottom must be provided for all vessels transiting a channel at any given time. Maximum vessel draft is that value which considers low water levels, vessel static conditions (salinity, trim, and list), wave motions, and squat. It is possible that a channel may not be of sufficient depth to accommodate a deep-draft vessel at extreme low tides. This factor must be evaluated depending on operational criteria.

7. WATER LEVELS. Determination of required operational depths involves analysis of probable water levels and vessel drafts. Hydraulic surveys and charts relate bottom elevations to local tidal datum planes. Water levels fluctuate, and both daily and extreme water level changes must be taken into consideration. Water-level excursions in a harbor range from relatively short-period waves, where water-surface slope can be visually observed, to long-period waves, where the water surface appears level to the observer. Protective breakwaters and seawalls are usually designed to provide shelter from waves with periods ranging from 0 to 20 seconds. Relatively longer period waves are normally considered to be waves having periods of greater than 20 to 30 seconds, including the periodic astronomical tides. In addition to periodic water-level variations, storm surges, tsunamis, and other phenomena should be considered when evaluating possible water-level conditions. Figure 13 shows examples of water-level fluctuations.

a. Astronomical Tides. Periodic forces on large bodies of water result from motions and mass attractions of the earth, moon, and sun. Through astronomical knowledge, the cyclic period of these force-producing constituents is known. Although the force-producing constituents are known, it is impossible to determine the resulting water motion (constituent amplitude and phase differences) at a particular location without field calibration.

(1) Predictions. For initial predictions of the tidal constants, an hourly record of water levels over a 29-day timespan is necessary. From this data, an approximation of astronomical water levels over the 19-year tidal epoch may be determined. Longer records are desirable to filter out nonastronomical effects that may have occurred during field measurements. Ongoing water-level gaging and astronomical tide prediction tables exist for numerous locations throughout the world. In U.S. territories, there is an existing network of long-term primary control tide stations, with associated shorter-record regional secondary control and subordinate tide stations. These are maintained by the U.S. National Ocean Survey (NOS).

(2) Classifications. Astronomical tides are classified as diurnal, semidiurnal, and mixed. Diurnal tides consist of a single high- and a single low-water level during the approximate 24-hour, 50-minute tidal day. Semidiurnal tides consist of two highs and two lows of similar amplitude over the tidal day. A mixed astronomical tide generally exhibits

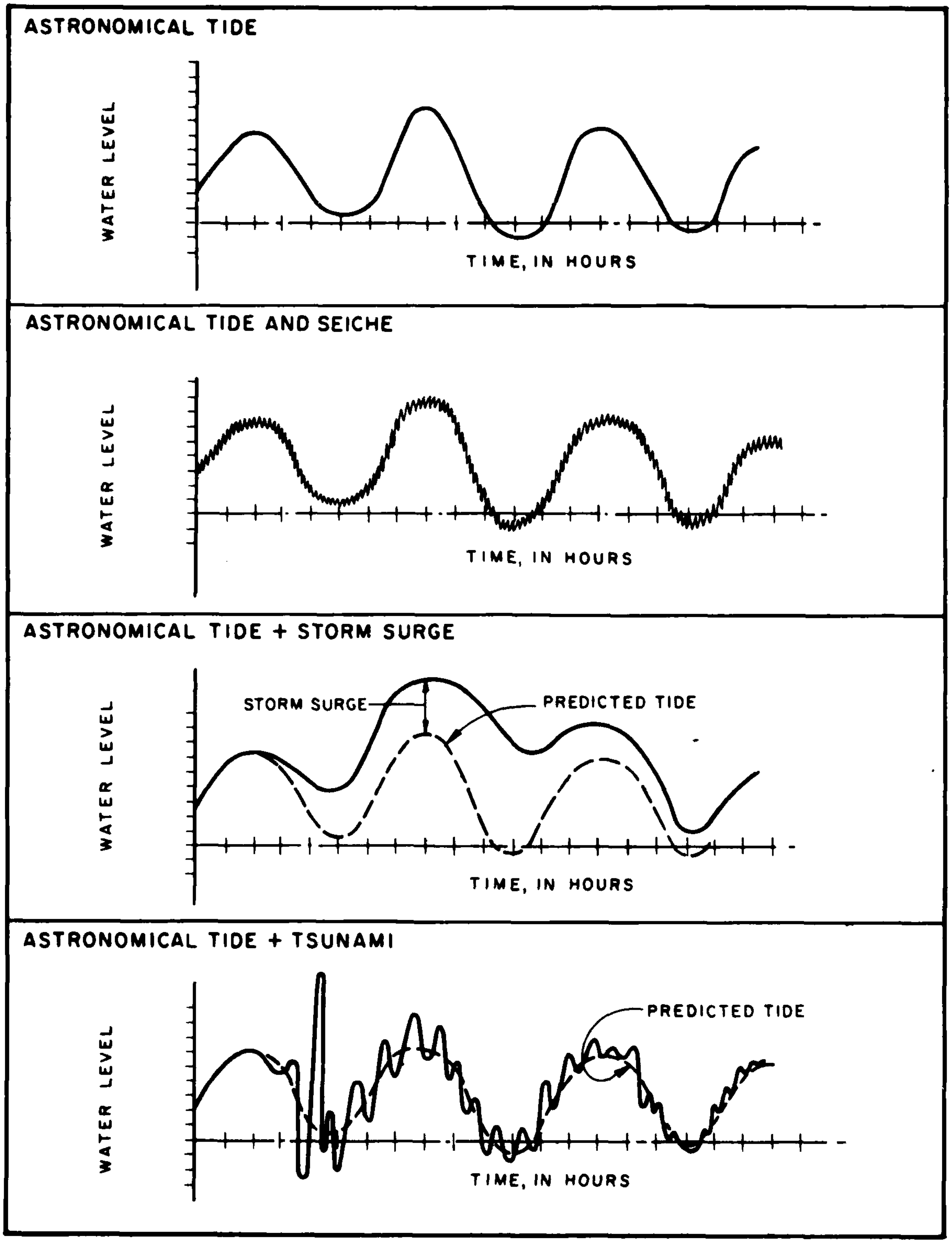


FIGURE 13
Examples of Water-Level Fluctuations

the semidiurnal period with noticeably different levels between succeeding high- and succeeding low-water periods. Examples of tide type and nomenclature are shown in Figure 14.

(3) Tide Datum. The averaging of all the high-water peak elevations over the 19-year tidal epoch provides the value of "mean high water" (MHW). Similarly, the averaging of low-water trough elevations provides a "mean low water" (MLW) value. Where mixed tides exist, consideration of the inequalities of the elevations of the two daily low tides is made by averaging only the lower of the two tides. This elevation, referred to as "mean lower low water" (MLLW), is commonly used as the hydrographic chart datum in locations of mixed tides. Similarly, "mean low water" (MLW) is the common chart datum in locations where diurnal tides predominate.

Tidal datum planes and observed extreme water levels (in feet) at selected U.S. naval facilities are listed in Table 6.

Tide-range values, as well as the MLW or MLLW datum planes, are, by definition, gage-specific. In preparing hydrographic charts, the basis of datum is often developed from temporary gages set in the area of survey.

Absolute elevations of water level can and do vary between adjacent gages. Figure 15 shows the locations of six tidal stations in the vicinity of San Diego. By converting the individual tidal datum of each station to the same upland datum, the differences in the absolute elevations of each gage can be seen. These differences are more pronounced in bays and estuaries than along long, straight coastlines. It is important to insure that astronomical tide estimates be applicable to the selected site.

b. Storm Tides. High-wind systems and low barometric pressures over shoaling water will create a temporary water-level rise along shorelines. Especially susceptible are areas where large cyclonic storm systems (such as hurricanes and typhoons) track across relatively shallow offshore water (100 fathoms or less). Preliminary analysis of the storm tide may be carried out as outlined in CERC Shore Protection Manual, Section 3.86. Where the potential for significant storm surge exists, and its accommodation becomes critical, more refined analysis should be made. Along coastal areas of the United States, estimates of storm-surge elevations have been prepared through numerical modeling techniques. These analyses include three-dimensional shoreline effects, probability of storm parameters, tracks, and joint occurrence of astronomical tide elevations. These estimates are available from the Federal Flood Insurance Agency of HUD and the U.S. Army Corps of Engineers.

c. Wave Setup. A relatively short-duration water-level rise (setup) will occur along coastlines during episodes of high-wave attacks. The rise in water level is caused by breaking waves trapping a water mass along the shoreline. This water rise, while accounted for in empirical wave-runup estimates (see Section 4, DM-26.2) for structural design, can increase water heights in protected water areas hydraulically linked to the coast, shoreward of the breaker line. This phenomenon, and generated currents associated with it, can be significant in harbor sites located behind reefs or large shoals. An approximation of the magnitude of water-level rise is shown in Figure 16.

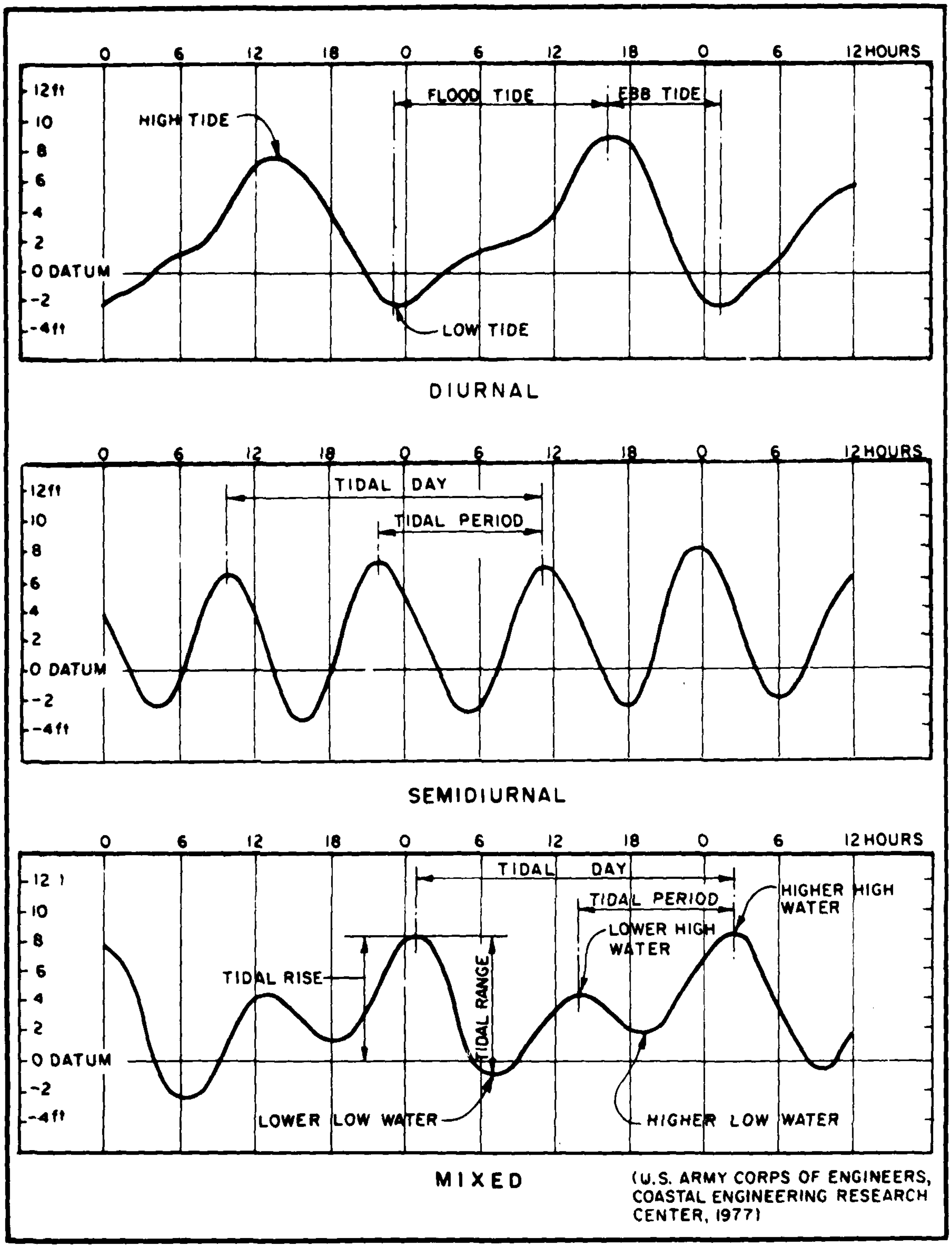


FIGURE 14
Types of Tides and Tide Nomenclature

TABLE 6
Tide Data for U.S. Naval Activities

Atlantic Naval Activities										
Location	Tide Station	Latitude/ Longitude	Extreme High Water Elev. (ft)	Extreme High Water Date	MHW (ft)	MLW (ft)	Extreme Low Water Elev. (ft)	Extreme Low Water Date	Difference NGVD-Gage Dat. (ft)	Observation Period
Annapolis, MD...........	Severn Riv.	38 59.1 76 26.2	6.3	23 Aug '33	0.9	0.0	-3.8	31 Dec '62	0.09	1941-59
Bayonne, NJ...........	Upper Bay	40 40.6 74 06.0	10	(Est.)	2.90	0.0	-4	(Est.)	1.69	Aug 1932
Block Is., RI...........	Block Is. Harbor (Old Harbor)	41 10.4 71 33.4	16.0	21 Sep '38	2.90	0.0	-3	(Est.)	1.09 (MLW Gage)	Jun-Aug 1938 Jun-Aug 1939
Boston, MA...........	Appresers Stores	42 21.3 71 03.0	15.2	7 Feb '78	4.5	0.3	-3.5	25 Jan '28	0.3 (MLW Gage)	1941-59
Cape May, NJ...........	Ferry Terminal	38 58.1 74 57.6	10.5	(Est.)	4.90	0.0	-3.5	(Est.)	1.96 (MLW Gage)	1970-75
Charleston, SC...........	Custom House Wharf, Cooper Riv. Entrance	32 46.9 79 55.5	10.7	11 Aug '40	5.51	0.31	-3.3	30 Nov '63	2.65 (MLW Gage) "Above Charleston Low Water Datum"	1941-59
Green Cove Springs, FL..	St. Johns River	29 59.7 81 40.5	3.5	(Est.)	0.80	0.0	-2.5	(Est.)	-0.03 (MLW Gage)	Mar-May 1935
Gulfport, MS...........	....	....	....	....	1.8	0.0	-2.5	....	MLW	....
Jackson-ville, FL....	(Acosta Bridge) St. Johns River	30 19.4 81 40.0	4	(Est.)	1.20	0.0	-2.5	(Est.)	-0.16 (MLW Gage)	Dec 1958- Mar 1959
Key West, FL...........	Key West Island	24 33.2 81 48.5	3.8	8 Sep '65	1.30	0.0	-1.6	12 Apr '74 19 Feb '28	0.42 (MLW Gage)	1941-59

TABLE 6
Tide Data for U.S. Naval Activities (Continued)

Atlantic Naval Activities										
Location	Tide Station	Latitude/ Longitude	Extreme High Water Elev. (ft)	Extreme High Water Date	MHW (ft)	MLW (ft)	Extreme Low Water Elev. (ft)	Extreme Low Water Date	Difference NGVD-Gage Dat. (ft)	Observation Period
Little Creek, VA....	Little Cr.	36 54.8 76 10.5	9	(Est.)	2.60	0.0	-3	(Est.)	1.38 (MLW Gage)	1954-59
Mayport, FL...........	St. Johns River	30 23.5 81 25.9	7.4	19 Oct '44	4.50	0.0	-3.2	24 Jan '40	2.00 (MLW Gage)	1941-59
Miami, FL....	Biscayne Bay	25 46.8 80 11.2	6	(Est.)	2.10	0.0	-2	(Est.)	0.73 (MLW Gage)	1970-71
Mobile, AL...........	Mobile Bay	30 42.4 88 02.6	9	(Est.)	1.50	0.0	-3	(Est.)	0.47 (MLW Gage)	1933-37 1960-61
Newark, NJ...........	....	....	10.5	....	5	0.0	-4	....	MLW	....
New London, CT...........	....	....	11.1	....	2.6	0.0	-3	....	MLW	....
Newport, RI...........	....	....	13.8	....	3.5	0.0	-2.6	....	MLW	....
Newport News, VA.....	....	....	10.0	....	2.6	0.0	-3.5	....	MLW	....
New York, NY...........	Battery	40 42.0 70 00.9	10.2	12 Sep '60	4.5	0.0	-4.2	2 Feb '76	1.81 (MLW Gage)	1941-59
Norfolk, VA...........	Hampton Roads	36 56.7 76 19.8	8.5	23 Aug '33	2.50	0.0	-3.1	31 Jan '66	1.28 (MLW Gage)	1941-59
Norfolk, VA...........	Portsmouth	36 49.3 76 17.6	9.2	23 Aug '33	2.80	0.0	-3.1	31 Jan '66	1.44 (MLW Gage)	1941-59

TABLE 6
Tide Data for U.S. Naval Activities (Continued)

Atlantic Naval Activities										
Location	Tide Station	Latitude/ Longitude	Extreme High Water Elev. (ft)	Extreme High Water Date	MHW (ft)	MLW (ft)	Extreme Low Water Elev. (ft)	Extreme Low Water Date	Difference NGVD-Gage Dat. (ft)	Observation Period
Patuxent, MD...........	Solomons Island	38 19.0 76 27.2	6.5	(Est.)	1.20	0.0	-3.5	(Est.)	0.38 (MLW Gage)	1941-59
Pensacola, FL...........	Pensacola Bay	30 24.2 87 12.8	8.9	20 Sep '26	1.30	0.0	-2.2	6 Jan '24	0.33 (MLW Gage)	1941-59
Philadelphia, PA...........	Municipal Pier 11 North	39 57.2 75 08.3	10.7	25 Nov '50	6.19	0.0	-6.6	31 Dec '62	2.28 (MLW Gage)	1967-1977
Portsmouth, ME......... .	Seavey Is.	43 04.9 70 44.7	12.5	7 Feb '78	8.10	0.0	-3.4	30 Nov '55	3.83 (MLW Gage)	1944-61
Providence, RI...........	State Pier No. 1	41 48.4 71 24.1	17.7	21 Sep '38	4.60	0.0	-3.4	5 Jan '59	1.85 (MLW Gage)	1939-46 1957-61
Salem, MA....	Salem	42 31.1 70 53.2	14.0	(Est.)	8.80	0.0	-3.5	(Est.)	....	27 May- 15 Jun '67 1-31 Aug '67 1-15 Sep '67
Savannah, GA...........	Savannah River	32 04.8 81 04.9	12.0	(Est.)	7.50	0.0	-4.5	(Est.)	3.37 (MLW Gage)	1934-35
Solomon, MD...........	....	....	6.5	....	1.2	0.0	-3.0	....	MLW	....
Thoms Cove, MD...........	....	....	....	....	1.1	0.0	-4.5	....	MLW	....
Wilmington, NC...........	Cape Fear River	34 13.6 77 57.2	8.2	15 Oct '54	4.20	0.0	-1.7	3 Feb '40	1.52 (MLW Gage)	1969-73

TABLE 6
Tide Data for U.S. Naval Activities (Continued)

Atlantic Naval Activities										
Location	Tide Station	Latitude/ Longitude	Extreme High Water Elev. (ft)	Extreme High Water Date	MHW (ft)	MLW (ft)	Extreme Low Water Elev. (ft)	Extreme Low Water Date	Difference NGVD-Gage Dat. (ft)	Observation Period
Bermuda Bio. Station......	Georges	32 22.2 64 41.8	4.7	22 Nov '61	2.40	0.0	-1.9	15 Mar '45 30 Apr '46 1 May '46	....	1945-59
Canal Zone, Panama.......	Cristobol Tide Sta.	9 21.2 79 54.8	1.4	....	0.32	-0.38	-1.2	....	....	1949-54
Grondal, Greenland....	....	....	....	....	7.5	1.0	....	....	MLWS	....
Narsarssuak, Greenland....	....	....	....	....	8.6	2.0	....	....	1.0 Ft Below MLWS	....
Reykjavik, Iceland......	....	....	....	....	11.4	2.2	....	....	0.5 Ft Below MLWS	....
Trinidad, B.W.I........	Carenage Bay	10 41.1 61 36.5	2.3	....	1.0	-1.0	-2.5	....	....	1950-51

NOTE: The datum for the Atlantic and Gulf coasts is currently being changed from MLW to MLLW. This change was not completed at the time of publication. Refer to current National Oceanic and Atmospheric Administration (NOAA) tide tables for tide data referenced to MLLW datum.

TABLE 6
Tide Data for U.S. Naval Activities (Continued)

Pacific Naval Activities										
Location	Tide Station	Latitude/ Longitude	Extreme High Water Elev. (ft)	Extreme High Water Date	MHHW (ft)	MLLW (ft)	Extreme Low Water Elev. (ft)	Extreme Low Water Date	Difference NGVD-Gage Dat. (ft)	Observation Period
Alameda, CA...........	S.F. Bay Naval Air Station	37 46.5 122 17.9	9.0	18 Jan '73	6.40	0.00	-2.2	12 Jun '68	3.03 (MLW Gage) "Above Lower Low Water Datum"	1941-59
Antioch, CA...........	San Joaquin River	38 01.2 121 48.9	7.0	(Est.)	3.71	0.00	-2.0	(Est.)	1.02 (MLW Gage)	1977-79*
Astoria, OR...........	Tongue Pt., Columbia River	46 12.5 123 46.0	12.1	17 Dec '33	8.30	0.0	-2.8	16 Jan '30	3.05 (MLW Gage)	1941-59
Bremberton, WA...........	Puget Sound	47 33.5 122 38.0	14.7	22-24 Dec '40	11.70	0.00	-4.5	30 Nov '36	....	1935-42
Hunters Point, CA....	S.F. Bay	37 43.8 122 21.4	9	(Est.)	6.60	0.0	-2.5	(Est.)	3.09 (MLW Gage)	1974-76*
Long Beach, CA...........	L.A. Outer Harbor	33 43.2 118 15.3	7.8	8 Jun '74	5.40	0.0	-2.6	26 Dec '32 11 Dec '33	2.72 (MLW Gage)	1941-59
Mare Island Strait, CA...	Bridge Over Mare Island	38 05.2 122 18.6	8.5	(Est.)	5.71	0.0	-2	(Est.)	2.50 (MLW Gage)	1977-78*
Port Hueneme, CA...........	Port Hueneme	34 08.9 119 12.2	7.6	4 Feb '58	5.40	0.0	-2.4	7 Jan '51	2.83 (MLW Gage)	1941-59
Port of Chicago, CA...........	Refugio Landing, San Pablo Bay	38 01.4 122 17.5	8.5	(Est.)	5.64	0.0	-2.5	(Est.)	2.51 (MLW Gage)	1976-77*

*Reduced to mean (1941-59)

TABLE 6
Tide Data for U.S. Naval Activities (Continued)

Pacific Naval Activities										
Location	Tide Station	Latitude/ Longitude	Extreme High Water		MHHW (ft)	MLLW (ft)	Extreme Low Water		Difference NGVD-Gage Dat. (ft)	Observation Period
			Elev. (ft)	Date			Elev. (ft)	Date		
San Diego, CA..........	San Diego Bay	32 42.8 117 10.4	8.3	20 Dec '68	5.70	0.0	-2.8	17 Dec '33 17 Dec '37	2.87 (MLW Gage)	1941-59
San Francisco, CA....	....	....	8.1	....	5.7	0.0	-2.5	....	MLLW	....
Seattle, WA..........	Puget Sound	47 36.2 122 20.2	14.8	15 Dec '77	11.30	0.0	-4.7	4 Jan '61 20 Jun '51	....	1941-59
Tacoma, WA..........	Commencement Bay, Puget Sound	47 15.3 122 26.0	15.5	(Est.)	11.80	0.0	-4.5	(Est.)	6.51 (MLW Gage)	1952-53
Balboa, Canal Zone.........	....	....	19.0	....	16.40	0.0	-4.0	....	MLWS	....
Dutch Harbor, AK..........	Amaknak Is., Aleutian Islands	53 53.5 166 32.2	6.6	14-15 Jan '38	3.70	0.0	-2.7	13 Nov '50	....	1935-38
Johnston Atoll, Hawaiian Is..	Johnston Atoll	16 44.7E 169 31.0W	5.1	13 Jan '58	2.10	0.0	-1.7	23, 24, 25 Mar '51	....	1950-51 1954-59
Kodiak, AK..........	Kodiak Island	57 47.3 152 24.0	13.0	(Est.)	8.50	0.0	-4	(Est.)	....	1935-36

*Reduced to mean (1941-59)

TABLE 6
Tide Data for U.S. Naval Activities (Continued)

Pacific Naval Activities										
Location	Tide Station	Latitude/ Longitude	Extreme High Water Elev. (ft)	Extreme High Water Date	MHHW (ft)	MLLW (ft)	Extreme Low Water Elev. (ft)	Extreme Low Water Date	Difference NGVD-Gage Dat. (ft)	Observation Period
Kwajalein Atoll, Marshall Is..	Kwajalein Island	8 44.2N 167 44.3E	3.71	15 Oct '62 Sep '63 6 Sep '67 25-26 Feb '71 8-9 Mar '74	1.74	-1.75	-3.59	7 Jan '58	....	1957-75
Marianas Is., N. Pacific Ocean........	Apra Harbor, Guam Island	13 26.5N 144 39.2E	1.9	....	0.99	-1.41	-3.3	....	....	1949-67
Massacre Bay, AK......	Attu Is., Aleutian Islands	52 50.4N 173 11.7E	7	(Est.)	3.30	0.0	-3	(Est.)	....	1944, 49,50 52, 61
Sand Is., Midway Is....	Sand Island	28 12.8 177 22.0	4.1	11 Jan '58	1.20	0.0	-1.0	6 Apr '69 5 May '69	....	1951-60
Sweeper Cove, AK.....	Adak Is., Aleutian Islands	51 51.7 176 38.6	7	(Est.)	3.70	0.0	-3.3	11 Nov '50	....	1958-60
Wake Island..	....	19 17.4 166 37.3	3.5	17 Jan '53	1.06**	-1.04**	-3.0	14 Apr '68 23 Oct '68	....	1951-69

**Diurnal tide--values for MHW and MLW, respectively

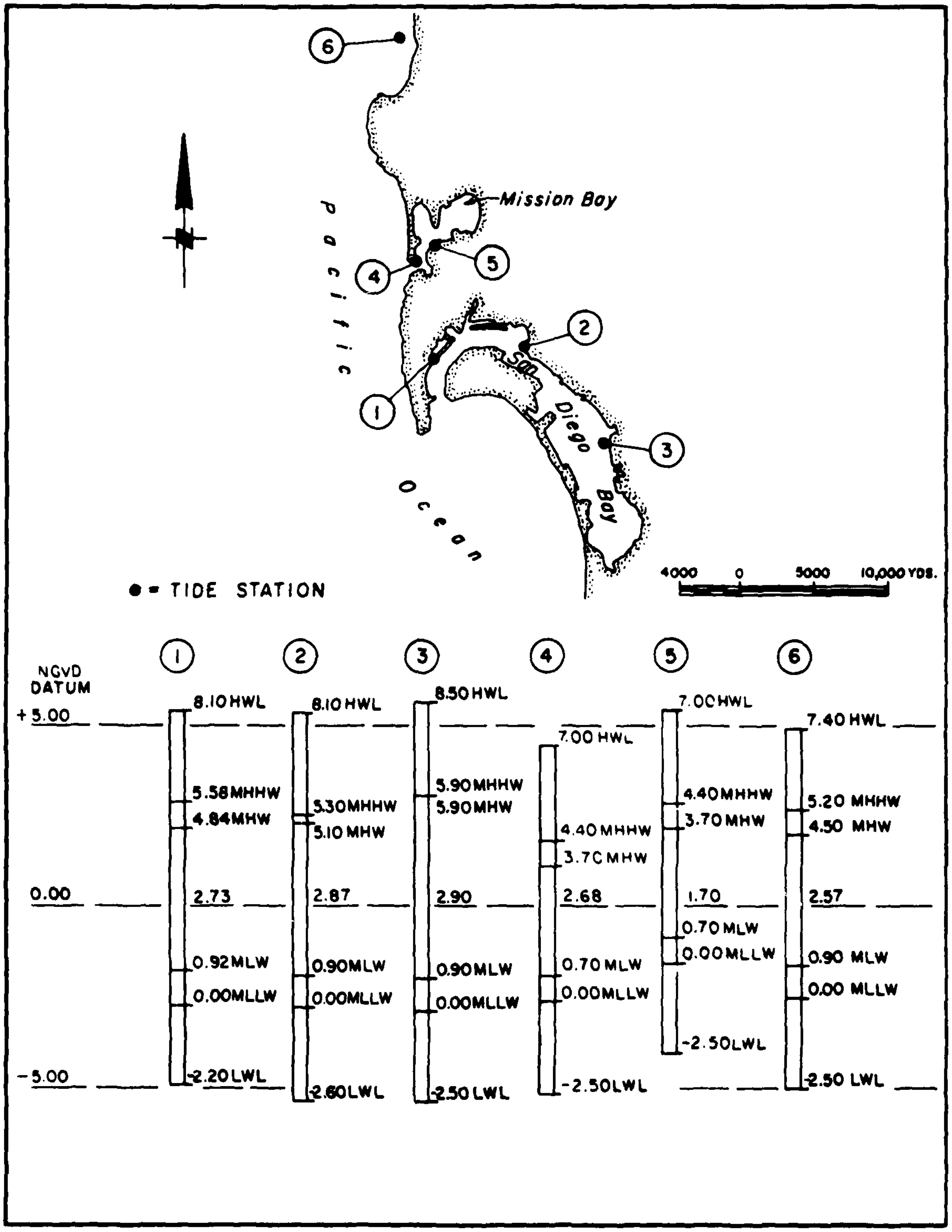


FIGURE 15
Comparison of Tidal Datum Planes

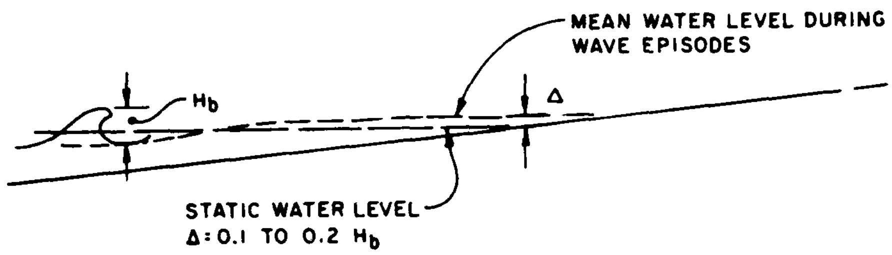


FIGURE 16
Wave Setup

d. Tsunamis. In certain ocean regions, waves generated by seismic disturbances or landslides do occur. From event history, some shoreline locations are more susceptible to damage from tsunamis than others. Probability approximations exist of water-level height at some coastal locations. These include reports by the U.S. Army Corps of Engineers and licensing studies by Public Utility Commissions. If warranted, a site-specific risk analysis can be performed which relies heavily upon probability parameters for specifics of the underwater seismic movement. This is coupled with a three-dimensional numerical analysis of ocean-basin propagation and near-shore site shoaling of the resulting long wave.

e. River Discharge. Where a harbor site is hydraulically influenced by river discharge, the present as well as future river flood discharge effects on water levels need to be considered.

f. Extreme Water Levels. Where a possible combination of events can produce extreme water-level conditions critical to the operation or safety of the harbor, notations of these circumstances and an estimate of the probability of their occurrence should be prepared.

8. SEICHE.

a. Basin Response. Seiche is defined as a standing-wave oscillation of an enclosed body of water that continues, pendulum fashion, after the cessation of the originating force, which may have been seismic or atmospheric. Seiche is a phenomenon associated with ocean waves having periods in excess of those of normal sea swell. Such waves, commonly known as "long waves," have periods ranging from 20 seconds to several hours. Long waves exhibit relatively low heights, on the order of 0.1 to 0.4 foot. They are highly reflective--even off flat-slope beaches--and will pass virtually unimpeded through porous breakwaters. Seiche occurs within a basin, harbor, or bay during certain critical wave periods when the period of incident long-wave energy matches the resonating period of the basin. The result is a standing-wave system comprising reinforced wave heights greater than those of the incident wave. The water surface

exhibits a series of nodes and antinodes with respect to the water column. Antinodes are regions where the vertical motion is a maximum and the horizontal velocities are minimum. Where wavelength is sufficiently greater than ship length, a ship berthed at the antinode will experience a gentle rise and fall with the standing-wave period. At the node, the ship will be subject to a periodic horizontal surging action due to currents. Figure 17 illustrates a typical, one-dimensional, standing-wave system.

b. Ship Response. A ship in combination with its mooring lines behaves as a spring-mass system which, when excited, can resonate at certain critical frequency ranges. During seiching action, the horizontal surging motion of a vessel located near a node can interfere with loading operations and, in severe cases, cause the mooring lines to part.

c. Investigations.

(1) Analyzing Seiche Potential. The causative force which sets a harbor basin into motion is long waves. These waves constitute a periodic forcing function, and, if the period of this forcing function is the same as the natural free oscillating period of the basin, then resonance will occur within the basin. The natural oscillating period of the basin is primarily a function of the basin geometry and water depth. Resonance will result in wave heights within the basin that are larger than most long-period wave heights outside the basin.

The potential for long-period wave activity at a particular selected harbor site must be investigated. Unfortunately, most undeveloped areas have little information regarding this potential. Even in developed areas, seiche activities are normally identified from resulting problems. Review of tide-gage records can sometimes result in an indication of seiche activities, provided that the gage is not located in a nodal area of the standing-wave system. Long-term field measurements with gage arrays can provide some insight into the areas susceptible to long-wave activities. At Capetown, South Africa, it has been suggested that the long-period wave activity may be related to some geophysical phenomena with a 7-year cycle. Due to uncertainty in the prediction of long-wave characteristics, harbor design consists primarily of avoiding basin geometries that make vessel berthing and moorings highly susceptible to seiche at any period. An analysis is essential when the particular area under consideration has a history of troublesome seiche at known periods.

Preliminary investigation of seiche for harbor basins consists of determining the natural or free oscillating period of the basin for various modes of oscillation, the standing-wave pattern at these periods, and the degree of amplification of wave heights within the basin for these periods. In general, harbor basins have varying depths and complex geometries. These characteristics lead to complex oscillations and standing-wave patterns. Analysis of such basins can only be done by sophisticated numerical or physical modeling. The results of an analysis for a relatively complex basin are shown in Figure 18. Figure 18A shows the layout of the basin. The degree of wave-height amplification within the basin is generally presented in a figure similar to Figure 18B. In the figure,

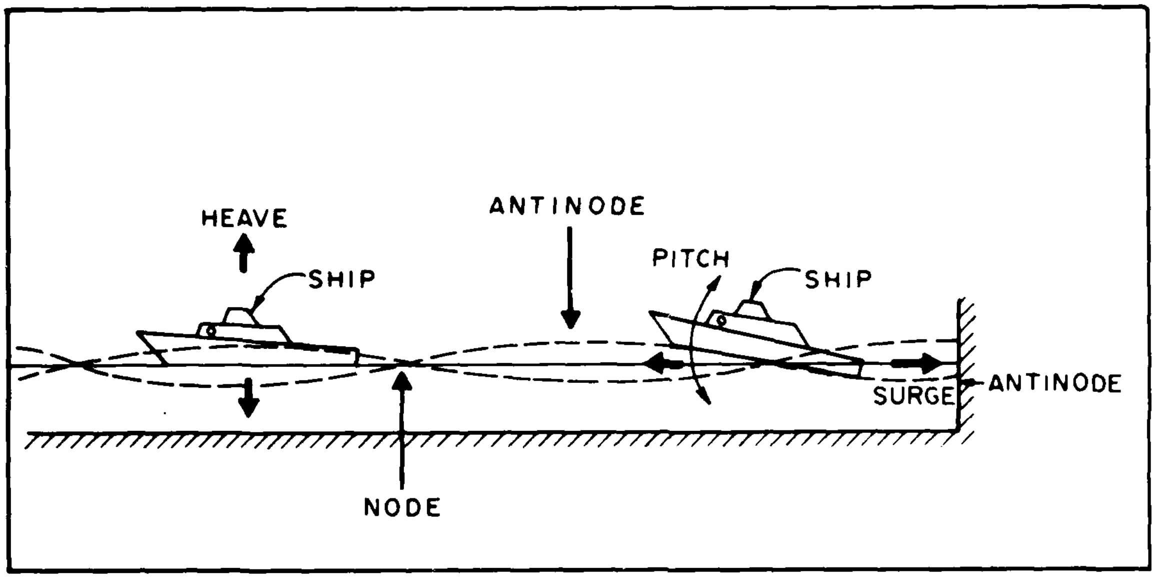


FIGURE 17
Typical One-Dimensional Standing-Wave System

the wave-height amplification factor (defined as the ratio of wave height in the basin to the incident wave height) is plotted against the wave period. This plot is constructed from information concerning the natural oscillating period of the basin for different modes of oscillation along with assumed incident wave energy. From this plot, the wave periods which cause severe wave amplification can be determined. Analysis of the wave climate for the harbor is necessary to determine whether or not the site is prone to wave energy at the critical wave periods. Figure 18C shows a standing-wave pattern associated with a particular resonating period and mode of oscillation. These patterns will shift with different modes and periods; thus, a complete analysis of seiche will require determining the standing-wave pattern and basin response for a series of resonating periods. Such an analysis is beyond the scope of this manual.

As a first approximation, the natural oscillating period of simple basins can be estimated. Approximations such as these can be useful in planning studies to determine whether the basin is prone to seiching or not.

In the case of a closed rectangular basin with vertical sides and constant depth, the natural oscillating period, T, is given by:

$$T = \left[2/\sqrt{gd}\right]\left[(n/l_b)^2 + (m/w_b)^2\right]^{-1/2} \qquad (2\text{-}1)$$

WHERE: T = natural free oscillating period, in seconds

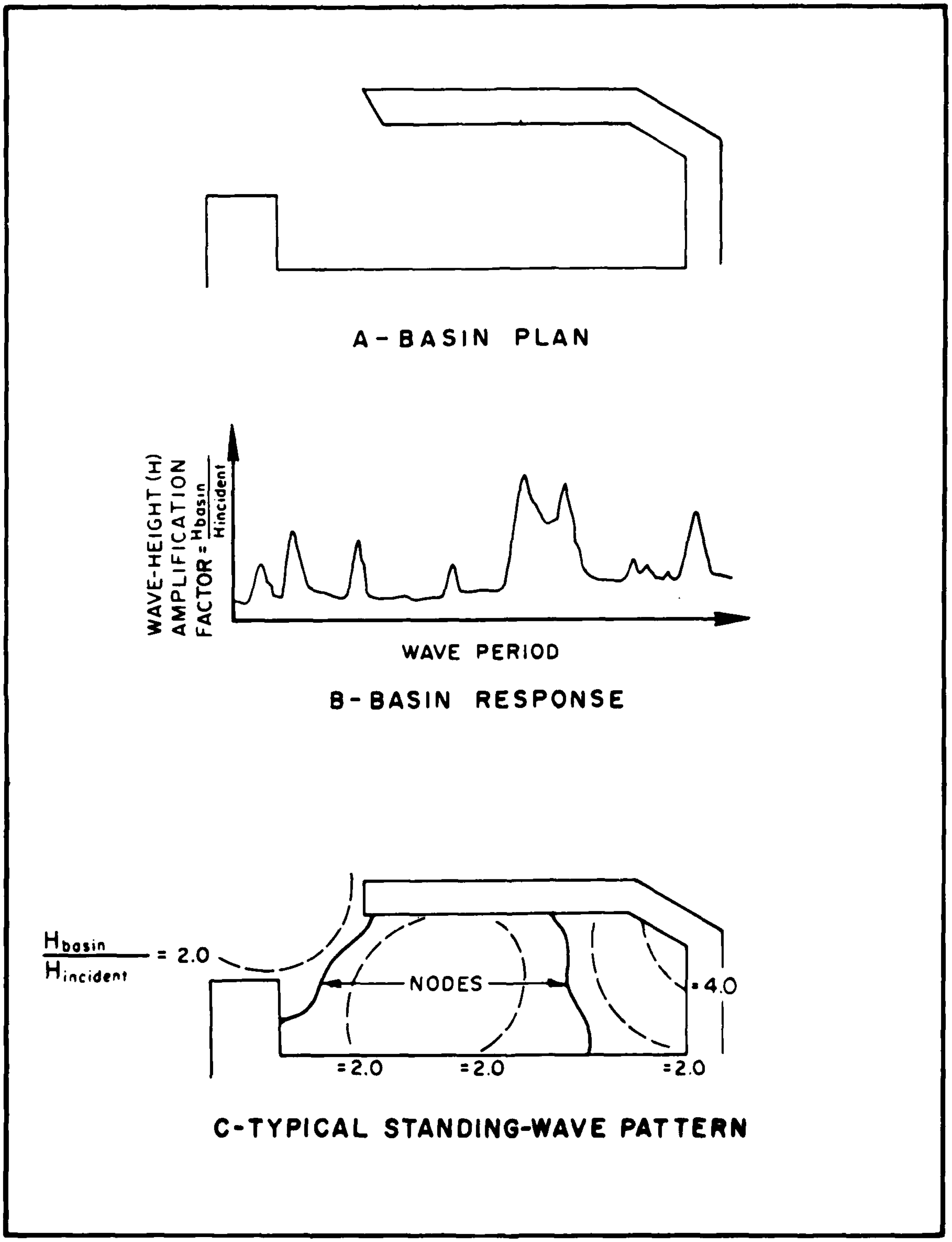


FIGURE 18
Basin Seiche Potential

d = basin depth, in feet

g = gravitational acceleration (32.2 feet per second^2)

l_b = length of basin, in feet

w_b = width of basin, in feet

n,m = integers representing the number of nodes in the l_b and w_b dimensions, respectively

For the case of a long and narrow basin, the equation reduces to:

$$T_n = 2\ l_b/n\sqrt{gd} \tag{2-2}$$

and there will be a node at the center of the basin, with antinodes at each end. For the fundamental (simplest) mode of oscillation in a closed basin, $n = 1$. The period, T_n, in this case becomes:

$$T_1 = 2\ l_b/\sqrt{gd} \tag{2-3}$$

Most harbor basins are not closed basins, but are open at the seaward end. The natural oscillating period, T_n, of a long and narrow open-ended basin is given by:

$$T_n = \frac{4\ l_b}{(1+2n)\sqrt{gd}} \tag{2-4}$$

WHERE: l_b = length of basin, in feet

g = gravitational acceleration (32.2 feet per second^2)

d = basin depth, in feet

n = number of nodes that occur between the node at the seaward opening and the antinode at the opposite end

In an open-ended basin, as stated above, there will be a node at the seaward opening and an antinode at the opposite end. For the fundamental mode, $n = 0$ and the period becomes =

$$T_0 = \frac{4\ l_b}{\sqrt{gd}} \tag{2-5}$$

EXAMPLE PROBLEM 2

Given: A narrow, open-ended basin of 1,500-foot length and 40-foot depth.

Find: The natural oscillating period for the fundamental, second, and third modes, and determine where the nodes occur within the basin.

EXAMPLE PROBLEM 2 (Continued)

Solution: l_b = 1,500 feet
d = 40 feet

(1) Fundamental mode ($n = 0$)

$$T_0 = \frac{4\ l_b}{\sqrt{gd}} = \frac{(4)(1,500)}{\sqrt{32.2(40)}} = 167 \text{ seconds}$$

For the fundamental mode, a node will occur at the seaward end of the basin and an antinode will occur at the landward end of the basin.

(2) Second mode ($n = 1$)

$$T_1 = \frac{4\ l_b}{(1+2n)\sqrt{gd}} = \frac{(4)(1,500)}{(3)\sqrt{(32.2)(40)}} = 55.73 \text{ seconds}$$

For a shallow-water wave:

$$L_1 = T\sqrt{gd} = 56\ \sqrt{(32.2)(40)} = 2,000 \text{ feet}$$

WHERE: L_1 = the length of the wave associated with the second mode of oscillation

The location of the nodes is as shown in Figure 19.

(3) Third mode ($n = 2$)

$$T_2 = \frac{4\ l_b}{(1+2n)\sqrt{gd}} = \frac{(4)(1,500)}{(5)\sqrt{(32.2)(40)}} = 33.44 \text{ seconds}$$

$$L_2 = T\ \sqrt{gd} = 33\sqrt{(32.2)(40)} = 1,200 \text{ feet}$$

WHERE: L_2 = the length of the wave associated with the third mode of oscillation

The locations of the nodes for the third mode are shown in Figure 20.

NOTE: This analysis will only give a general indication as to whether seiche is a potential problem for the given basin layout. If analysis of wave climate suggests there is wave energy present at the oscillating periods, then further analysis is required.

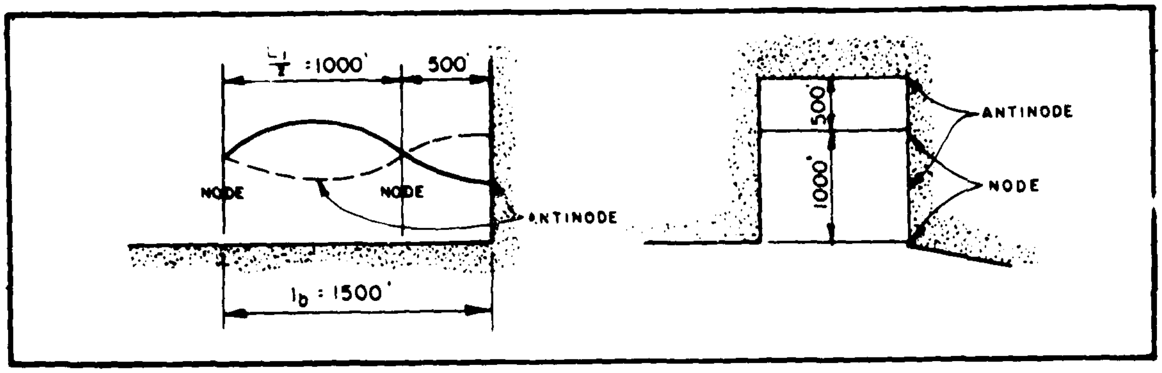


FIGURE 19
Locations of Nodes for Second Mode of Oscillation in Example Problem 2

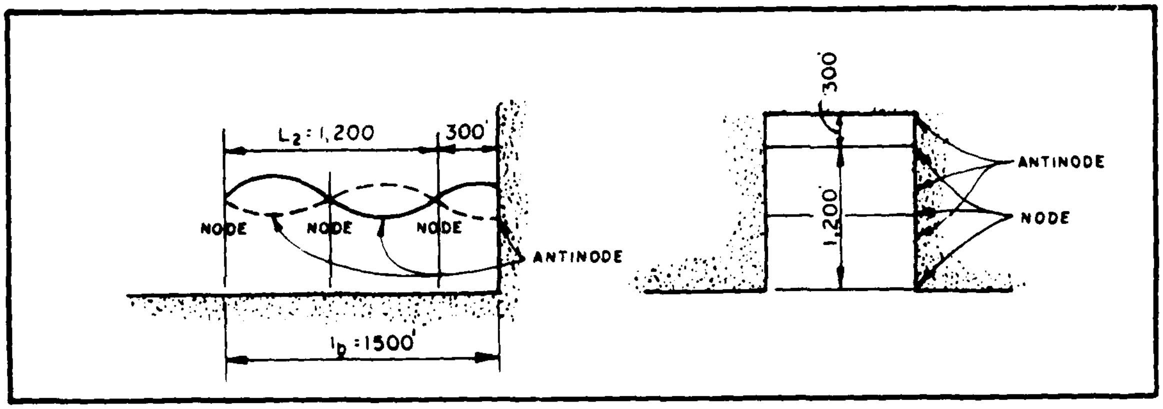


FIGURE 20
Locations of Nodes for Third Mode of Oscillation in Example Problem 2

(2) Analysis of Ship-Response Characteristics. The objective of a response analysis is to determine the amplitude of the mooring-line forces for a ship acted on by a seiche motion of given amplitude. The basic procedure is to equate the summation of forces on the vessel to its mass times acceleration. In actuality, six equations may be written for corresponding accelerations along and angular accelerations around the three perpendicular axes. These comprise six degrees of freedom and are shown schematically in Figure 21. The general problem consists of solving the coupled motions in six degrees of freedom of a ship moored in waves under nonlinear restraints from mooring lines and fenders. When a vessel is subjected to seiching action, although the amplitude of seiche is generally low, the vessel is subjected to a surging motion. Thus in practice only the motion in surge (along the ship's axis) and in sway (athwart ships) are normally important for purposes of mooring design. (For design of moorings, see DM-26.5.) In either direction, the general force equation is of the form:

$$F_w + F_D + F_m + F_I = 0 \qquad (2\text{-}6)$$

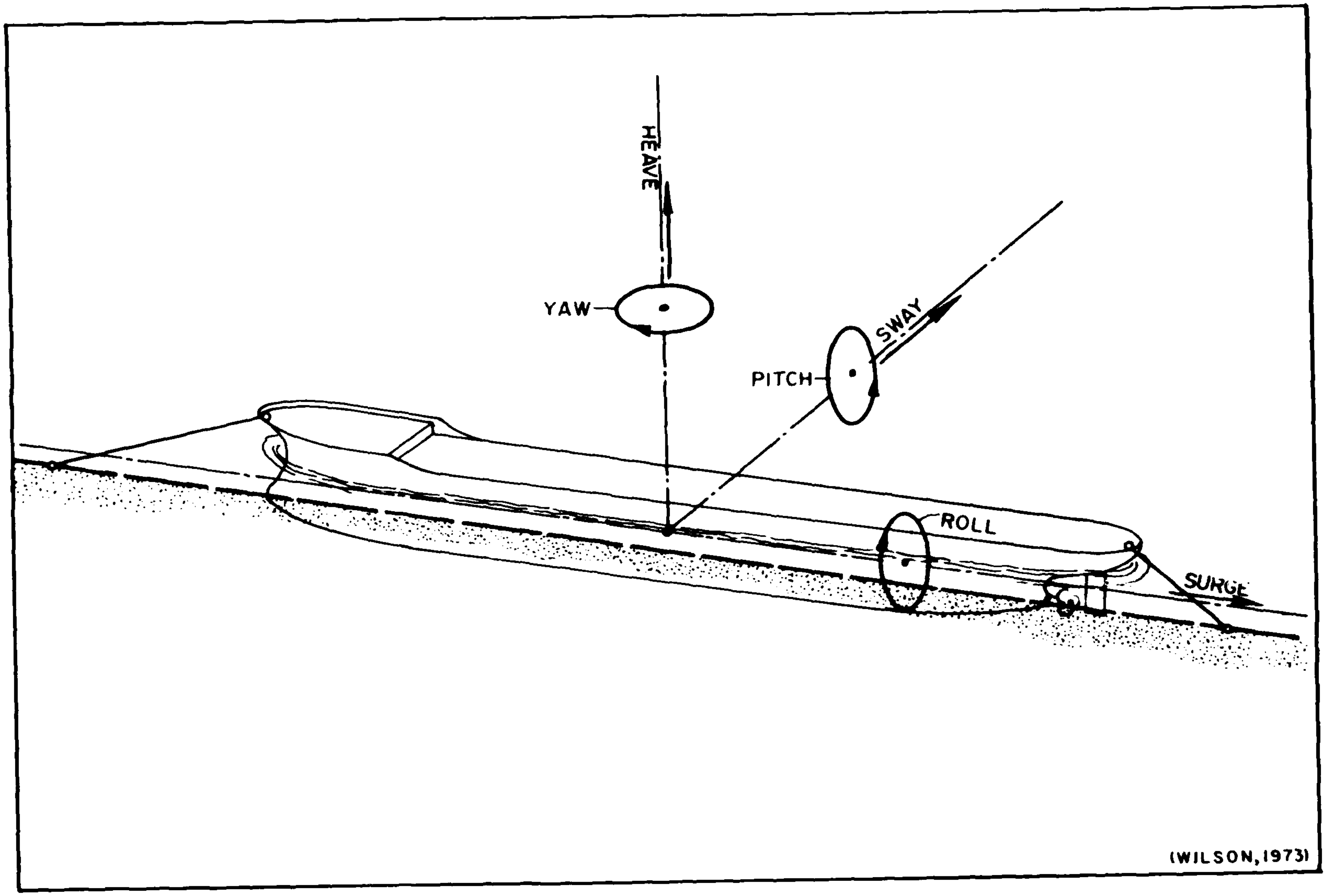


FIGURE 21
Six Degrees of Freedom

WHERE: F_w = wave-pressure force

F_D = drag force

F_m = mooring-restraint force

F_I = inertial force

Solution of the above equation is a complicated procedure involving several simplifying assumptions. Solutions are best achieved through the use of numerical models. These models are complex and beyond the scope of discussion here. The results of such analysis may be presented in a figure similar to Figure 22. In this figure the amplitude of surge movement of the vessel is plotted against seiche period for a given seiche amplitude. As shown in the figure, the vessel may resonate at critical seiche periods, causing large motions in surge. After determination of the magnitude of surge motion, assessment of the potential hazards to cargo handling, vessel damage, and mooring breakage may be made.

d. Corrective Measures. Little can be done to prevent long waves from entering a harbor. There are three basic approaches to mitigation of problems incurred by seiche:

(1) Adjust the geometry or depth of the basin such that the natural oscillating period of the basin is adjusted away from the critical periods of the incident wave energy.
(2) Locate berths within the harbor basin away from the seiche nodes in order to avoid regions where vessels are subject to large surging motions.
(3) Tighten the mooring lines on vessels to aid in reducing the amplitude of surge movement when the vessel is subjected to seiche.

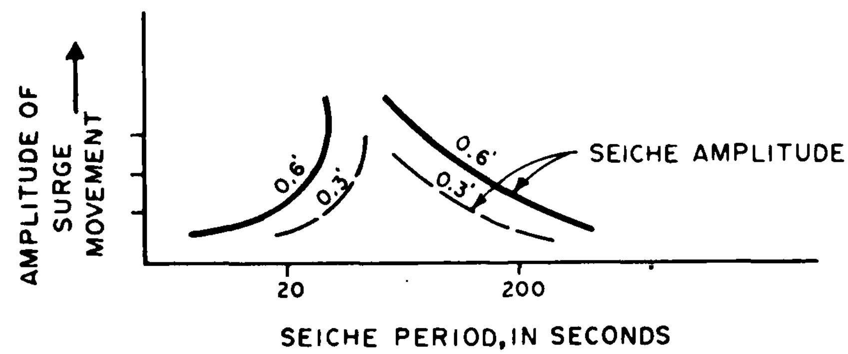


FIGURE 22
Amplitude of Surge Movement of Vessel Subjected to Seiche

9. CURRENTS.

a. Entrance Widths. Entrance widths should be adequate to reduce currents to acceptable values. The maximum allowable current in an entrance channel is a function of the type of ship or ships to be accommodated. Only under special circumstances should the current exceed 4 knots.

(1) If the entrance is not constrictive (Figure 23) and the following conditions are fulfilled:

(a) the basin is relatively short and deep; that is:

$$\frac{l_b}{(\sqrt{gd})(T)} \leq 0.05 \qquad (2\text{-}7)$$

WHERE: l_b = basin length, in feet

d = average basin depth, in feet;

(b) the bay water area is relatively constant;
(c) freshwater inflow is minimal; and
(d) the ocean tide is approximately sinusoidal,
then a good approximation for the current velocity is:

$$\bar{V}_m = \frac{2\Pi a_s A_b}{A_c T} \qquad (2\text{-}8)$$

WHERE: $\bar{V}_m$ = average cross-section velocity at maximum tidal flow, in feet per second

T = period of tide, in seconds

A_b = surface area of basin, in square feet

A_c = cross section of opening at mean tide level, in square feet

a_s = 1/2 range of the ocean tide, in feet

The entrance not being constrictive, together with condition (a) (Equation 2-7), imply that the water surface in the bay fluctuates uniformly and equals the ocean tide.

EXAMPLE PROBLEM 3

Given: a. A rectangular basin with a nonconstricting entrance
b. Basin length, l_b = 10,000 feet
c. Basin depth, d = 30 feet
d. Basin width at the entrance = 500 feet
e. Semidiurnal tidal range = 6.0 feet; (T = 12.4 hours)

Find: The average cross-section velocity at the opening.

EXAMPLE PROBLEM 3 (Continued)

Solution: (1) Determine if assumption (a) (Equation 2-7) is valid:

T = (12.4 hours)(3,600 seconds/hour) = 44,640 seconds

$$l_b/(gd)^{1/2}T = 10{,}000/\left[(32.2)(30)\right]^{1/2}(44{,}640)$$

$$= 0.0072 < 0.05$$

Therefore, the assumption (a) (Equation 2-7), that the basin is relatively short and deep, is satisfied. For the purpose of this example, it will be assumed that the other assumptions are valid.

(2) Determine $\bar{V}_m$:

a_s = 6.0/2 = 3.0 feet

A_b = (500)(10,000) = 5,000,000 square feet

A_c = (500)(30) = 15,000 square feet

$$\bar{V}_m = \frac{2\Pi a_s A_b}{A_c T} = \frac{2\Pi(3.0)(5{,}000{,}000)}{(15{,}000)(44{,}640)}$$

$\bar{V}_m$ = 0.1408 feet per second

Conversion: 1 knot = 1.688 feet per second

$\bar{V}_m$ = (0.1408 feet per second)/(1.688 feet per second/knot)

$\bar{V}_m$ = 0.08 knot

(2) If the entrance is constrictive (Figure 24), thereby reducing the tide range in the bay, the above expression will overestimate the tidal currents. Provided the conditions (a) through (d) outlined in (1) are satisfied, the maximum current in the entrance can be determined from:

$$\bar{V}_m = \frac{2\Pi a_s A_b e}{A_c T} \qquad (2\text{-}9)$$

WHERE: $\bar{V}_m$ = average cross-section velocity at maximum tidal flow, in feet per second

A_c = cross section of opening at mean tide level, in square feet

T = period of tide, in seconds

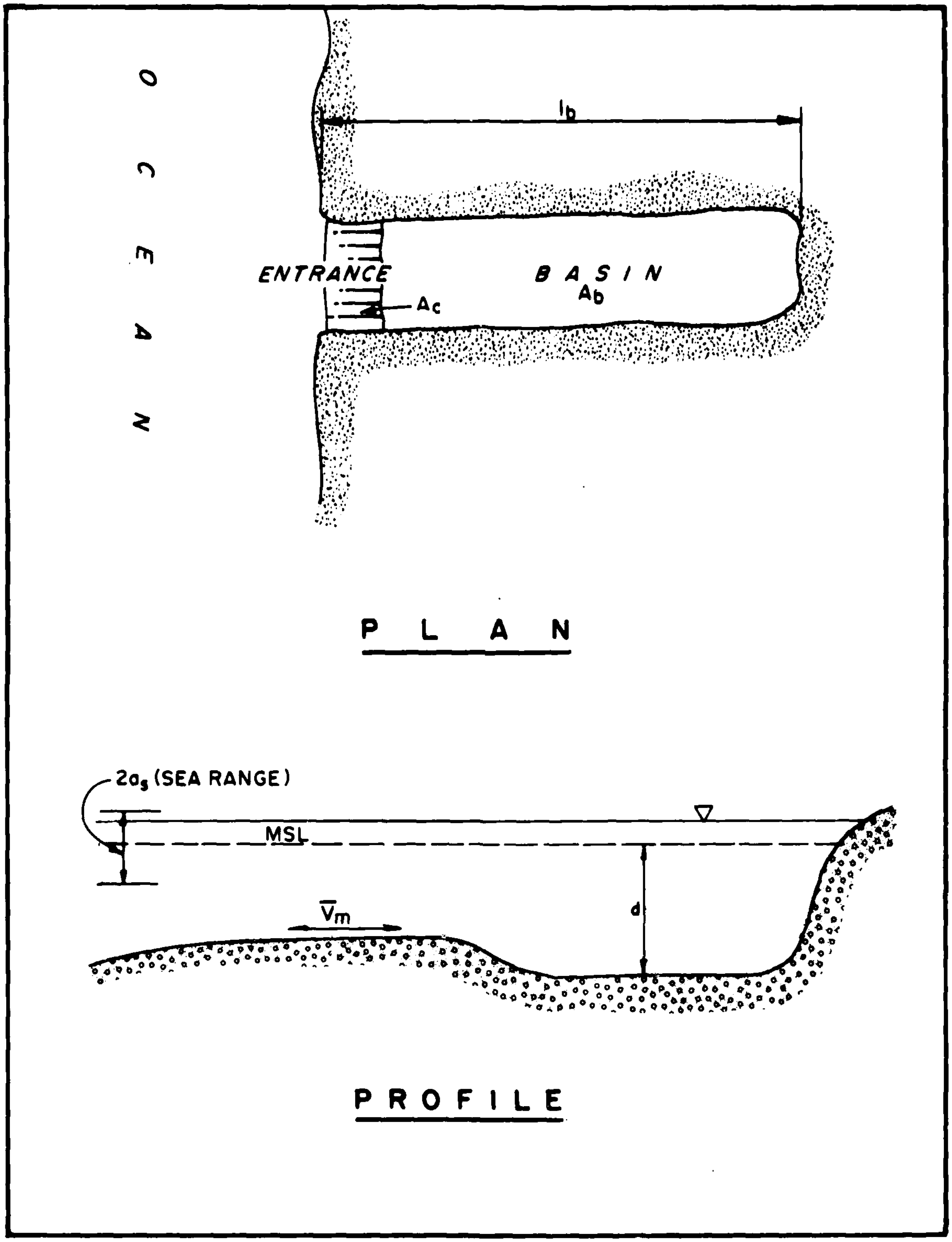


FIGURE 23
Basin With Nonconstricted Entrance

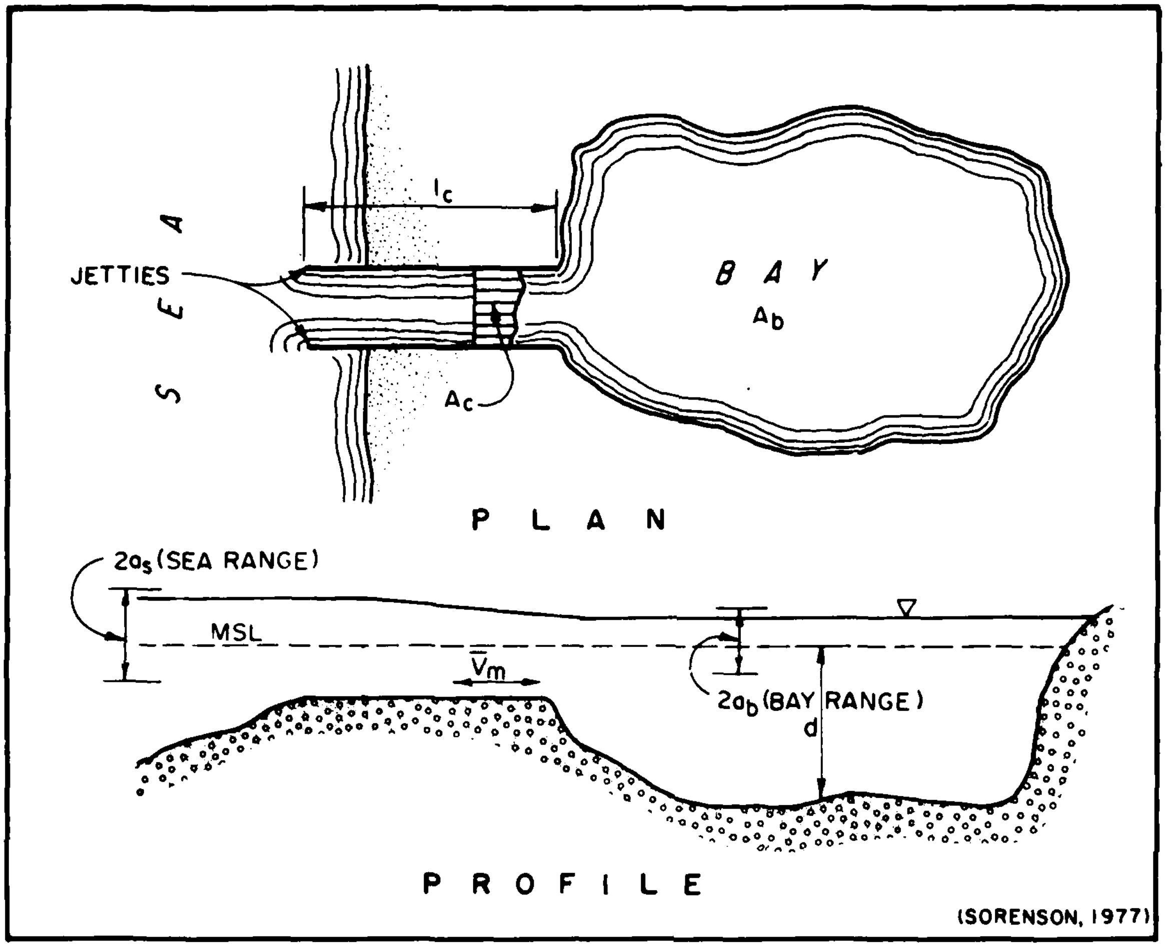


FIGURE 24
Sea-Inlet-Bay System

a_s = 1/2 range of the ocean tide, in feet

A_b = surface area of bay, in square feet

e = a dimensionless factor which depends on coefficients K_1 and K_2; see Figure 25

The coefficients K_1 and K_2 are defined as follows:

$$K_1 = \frac{a_s A_b F_c}{2\ l_c\ A_c} \tag{2-10}$$

$$K_2 = \frac{2\Pi}{T}\sqrt{\frac{l_c\ A_b}{g\ A_c}} \tag{2-11}$$

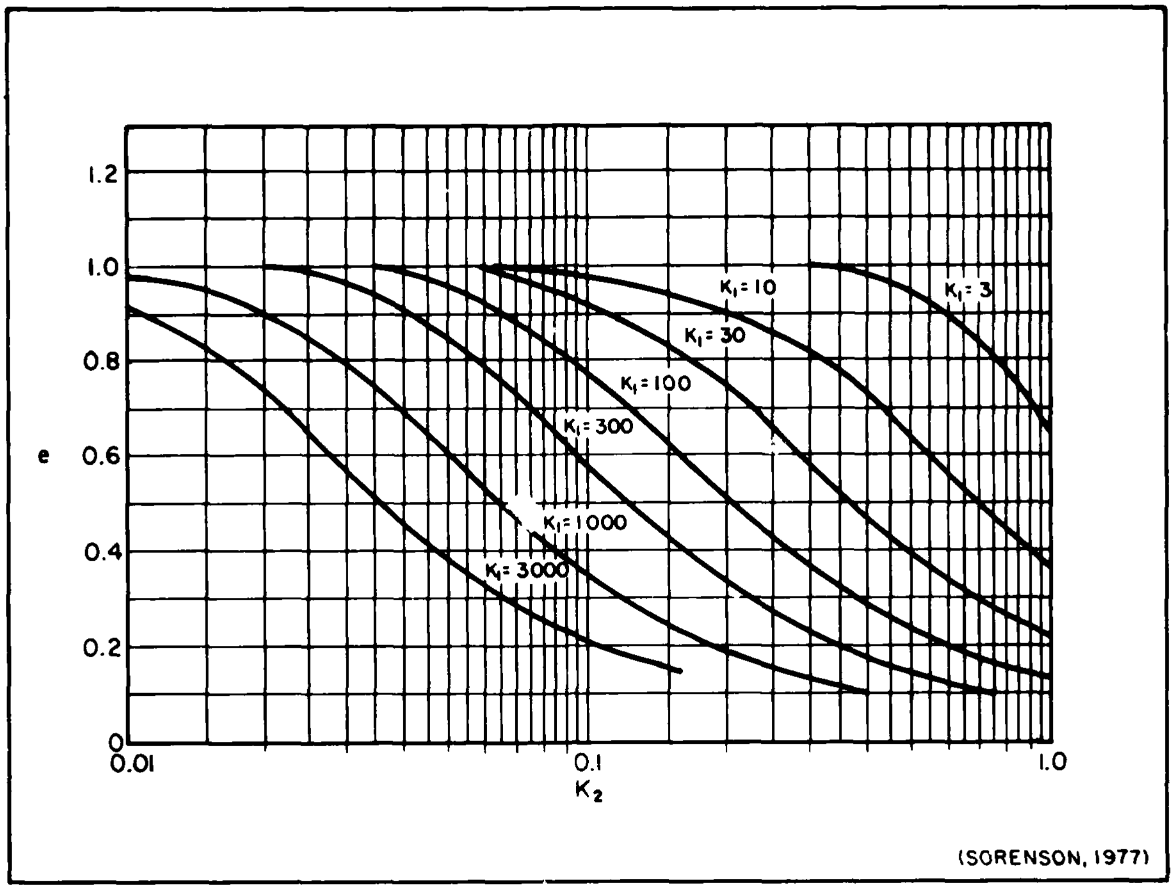


FIGURE 25
Dimensionless Maximum Velocity Versus K_1 and K_2

WHERE: l_c = channel length, in feet

F_c = $(k_{en}+k_{ex}+fl_c/4R)$

k_{en} = entrance-loss coefficient (approximately 0.1)

k_{ex} = exit-loss coefficient (approximately 1.0)

f = Darcy-Weisbach friction factor (approximately 0.03)

R = hydraulic radius of inlet channel, in feet

K_1 represents the ratio of the magnitude of the friction forces and inertia forces. K_2 is a measure of the magnitude of the inertia forces relative to the magnitude of the pressure (water-level) gradient.

Because the entrance is constrictive, the amplitude of the bay tide will differ from the amplitude of the tide range in the ocean. The bay-tide

amplitude may be determined from:

$$\frac{a_b}{a_s} = \varepsilon \tag{2-12}$$

WHERE: ε = a dimensionless factor which depends on the coefficients K_1 and K_2; see Figure 26

a_b = 1/2 range of bay tide, in feet

It is noted that for small values of K_1 (large inertia forces) the value of ε is greater than one.

For irregular entrance channels, an effective channel length, l'_c, can be used in place of l_c.

$$l'_c = \sum_{1}^{n} (\overline{R}/R_n)(\overline{A}_c/A_n)^2 \Delta X_n \tag{2-13}$$

WHERE: $\overline{R}$ = average hydraulic radius of channel, in feet

$\overline{A}_c$ = average cross section of channel at mean tide level, in square feet

R_n = hydraulic radius at each of n sections of equal length, ΔX_n, in feet

A_n = cross section of channel at each of n sections of length, ΔX_n, in square feet

EXAMPLE PROBLEM 4

Given:
a. Constricted entrance channel
b. Bay area, A_b = 25 square miles
c. Longest length of bay, l_b = 7 miles
d. Entrance channel depth = 40 feet
e. Entrance channel width = 800 feet
f. Entrance channel length, l_c = 4,000 feet
g. Semidiurnal tidal range = 6.5 feet; (T = 12.4 hours)
h. Average depth of bay, d = 30 feet

Find: The maximum average cross-section velocity in the entrance channel, and the tidal range within the bay.

Solution: (1) Determine if assumption (a) (Equation 2-7) is valid:

l_b = (7 miles)(5,280 feet per mile) = 36,960 feet

T = (12.4 hours)(3,600 seconds per hour) = 44,640 seconds

EXAMPLE PROBLEM 4 (Continued)

$$l_b/(gd)^{1/2}T = 36{,}960/\left[(32.2)(30)\right]^{1/2}(44{,}640)$$

$$= 0.027 < 0.05$$

Therefore, the assumption concerning the length of the bay (Equation 2-7) is satisfied. For the purposes of this example, it will be assumed that the other assumptions are also satisfied.

(2) Determine $\bar{V}_m$ and a_b (1/2 tidal range):

$a_s = 6.5/2 = 3.25$ feet

$A_c = (40)(800) = 32{,}000$ square feet

$A_b = (25 \text{ square miles})(5{,}280 \text{ feet per mile})^2$

$A_b = 6.97 \times 10^8$ square feet

Assuming a rectangular cross section:

$R = A_c/\left[800+(2)(40)\right]$

$R = 32{,}000/880 = 36.36$ feet

Determine K_1:

$F = k_{en} + k_{ex} + fl_c/4R$

$F = 0.1 + 1.0 + \left[(0.03)(4{,}000)/(4)(36.36)\right] = 1.93$

$$K_1 = \frac{a_s A_b F}{2\, l_c A_c} = \frac{(3.25)(6.97 \times 10^8)(1.93)}{(2)(4{,}000)(32{,}000)}$$

$K_1 = 17.08$

Determine K_2:

$$K_2 = \frac{2\Pi}{T}\sqrt{\frac{l_c A_b}{g\, A_c}} = \frac{2\Pi}{44{,}640}\sqrt{\frac{(4{,}000)(6.97 \times 10^8)}{(32.2)(32{,}000)}}$$

$K_2 = 0.232$

From Figure 25 for calculated values of K_1 and K_2:

$e = 0.81$

THEREFORE: $$\bar{V}_m = \frac{2\Pi\, a_s A_b e}{A_c\, T} = \frac{2\Pi(3.25)(6.97 \times 10^8)(0.81)}{(32{,}000)\ (44{,}640)}$$

EXAMPLE PROBLEM 4 (Continued)

$\bar{V}_m$ = 8.07 feet per second

Conversion: 1 knot = 1.688 feet per second

$\bar{V}_m$ = (8.07 feet per second)/(1.688 feet per second/knot)

$\bar{V}_m$ = 4.78 knots

Note: This velocity is higher than the 4-knot maximum and is not desired. For an actual design, the entrance should be modified to lower the velocity.

From Figure 26 for the calculated values of K_1 and K_2:

$\varepsilon = a_b/a_s = 0.94$

THEREFORE: $a_b = a_s\ (0.94)$

$a_b = (3.25)(0.94)$

a_b = 3.06 feet

a_b = 1/2 range of bay tide

range of bay tide = $2a_b$

range of bay tide = (2)(3.06)

range of bay tide = 6.12

range of ocean tide = 6.5

6.5-6.12 = 0.38

Therefore, the tidal range in the bay is reduced by 0.38 feet from the ocean tidal range.

The analysis presented above provides an estimate of the channel-inlet hydraulics applicable to design situations. However, if the assumptions presented in (1) are not satisfied, or if the current velocities are critical to the channel design, more detailed analysis, using mathematical- or physical-model simulation, is required.

10. METRIC EQUIVALENCE CHART. The following metric equivalents are approximate and were developed in accordance with ASTM E-621. These units are listed in the sequence in which they appear in the text of Section 2. Conversions are approximate.

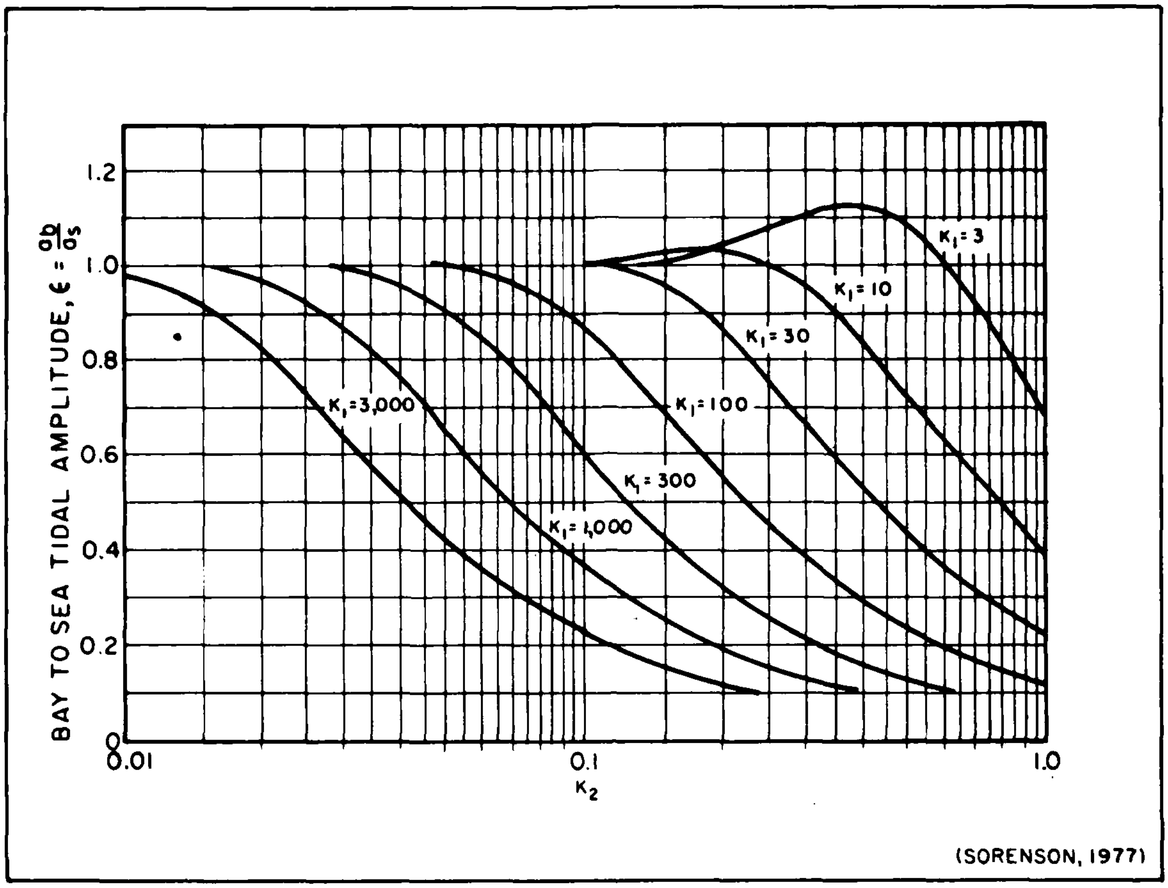


FIGURE 26
Ratio of Bay to Sea Tidal Amplitude Versus K_1 and K_2

4 feet = 1.2 meters
2 feet = 61 centimeters
7 knots = 3.6 meters per second
8 knots = 4.1 meters per second
45 feet = 13.7 meters
36 feet = 11.0 meters
5 feet = 1.5 meters
12 feet = 3.7 meters
15 feet = 4.6 meters
4 inches = 10 centimeters
100 feet = 30.5 meters
32 feet = 9.8 meters
113 feet = 34.4 meters
500 feet = 152.4 meters
0.1 foot = 3.05 centimeters
0.4 foot = 12.19 centimeters
32.2 feet per second = 9.81 meters per second
4 knots = 2.0 meters per second

Section 3. LAYOUT OF FACILITIES

1. HARBOR ENTRANCE. Design of approach-channel and entrance-channel widths for harbors located in exposed ocean-wave environments is primarily accomplished through comparison of presently operating harbors. The forces of waves and currents acting on a vessel in exposed locations induce excursions of the vessel from its intended path of travel. To pass in the lee of an entrance structure, a vessel requires maneuvering room in order to adjust to the rapid change in sea conditions. Where naval activities share common entrance approaches with commercial port activities, entrance-channel widths in excess of 1,000 feet are common. Table 7 gives entrance-channel dimensions for several typical harbors. Typical harbor entrances serving naval facilities are listed in Table 8. For new entrance designs, preliminary width approximations can be made, as discussed in the paragraph in this section entitled, "Entrance Channels," by adjusting ship beam with yaw angle increase and proceeding as for an interior-channel design. Where the hydraulic environment at the entrance is unique and without precedent, navigational studies involving suitable-scale physical model methods are recommended.

2. SHIP CHANNELS.

a. Interior Channels. The dimensioning of interior channels protected from open sea waves and strong cross currents is shown in Figure 27, where B = beam of vessel.

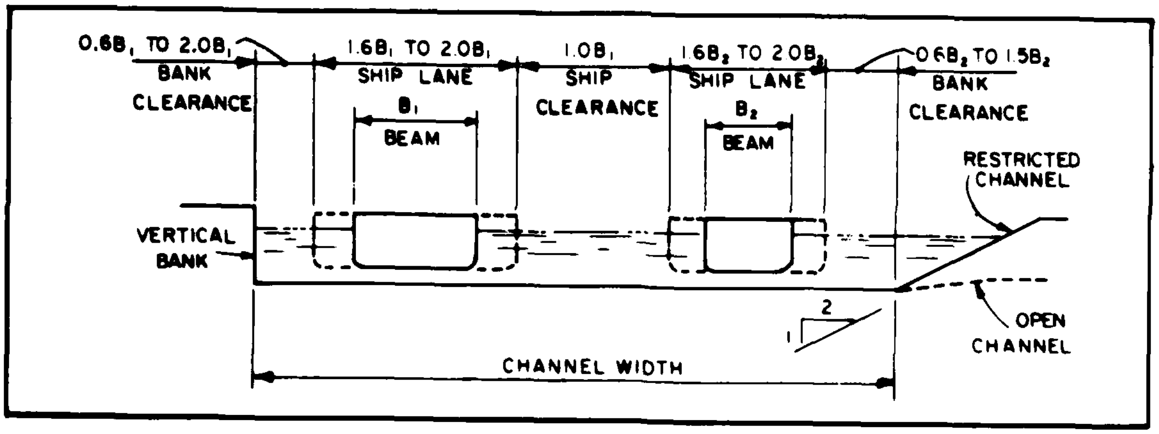


FIGURE 27
Dimensioning Protected Interior Channels

(1) Ship-Lane Widths. Where good operating conditions (that is, a maximum ship speed of 10 knots, currents less than 3 knots, good visibility, and wind less than 15 knots) exist, the following ship-lane widths should be used:

TABLE 7
Typical Entrance-Channel Dimensions

Harbor	Width (ft)	Depth (ft)	Remarks
Boston, MA	1,100	40	Access to port entrance
New York, NY	1,800	44	Access to port entrance
Charleston, SC	1,500	35	Nonrestricted outlet for three rivers
Columbia River, OR	2,640	48	River bar crossing in severe wave environment--closed during certain storms
Long Beach, CA	1,800	60	Breakwater gap
San Diego, CA	800	41	Entrance channel through parallel jetties
Apra Harbor-Guam	1,350	120	Entrance between breakwater head and shore

TABLE 8
Typical Harbor Entrances Serving Naval Facilities

Harbor	Width (ft)	Depth (ft)	Largest Naval Vessel--Normal Use	Remarks
May Port, FL	900	42	Unrestricted	Entrance through parallel jetties
Port Hueneme, CA	600	39	Destroyer	Entrance through non-parallel jetties
Pearl Harbor, HI	1,580	60	Unrestricted	Broad, ill-defined entrance
Seal Beach, CA	600	38	Destroyer	Entrance through non-parallel jetties

Vessel Maneuvering Characteristics	Lane Width as a Multiple of Beam
Excellent--CG and DD	1.6
Good--FFG, CV, AOE, and LSD 36	1.8
Poor--Submarines, Tenders, AE, and AS	2.0

(2) Ship Clearance. Ship clearance is normally assumed to be equal to the beam at waterline of the largest vessel. Where a channel is to be frequently used by aircraft carriers having large overhanging decks, increase the clearance between ship lanes to maximum vessel breadth.

(3) Bank Clearance. Vessels traveling in restricted waterways experience hydrodynamic suction from the banks. This is offset by rudder-angle adjustment. Results of limited model studies are shown in Figure 28.

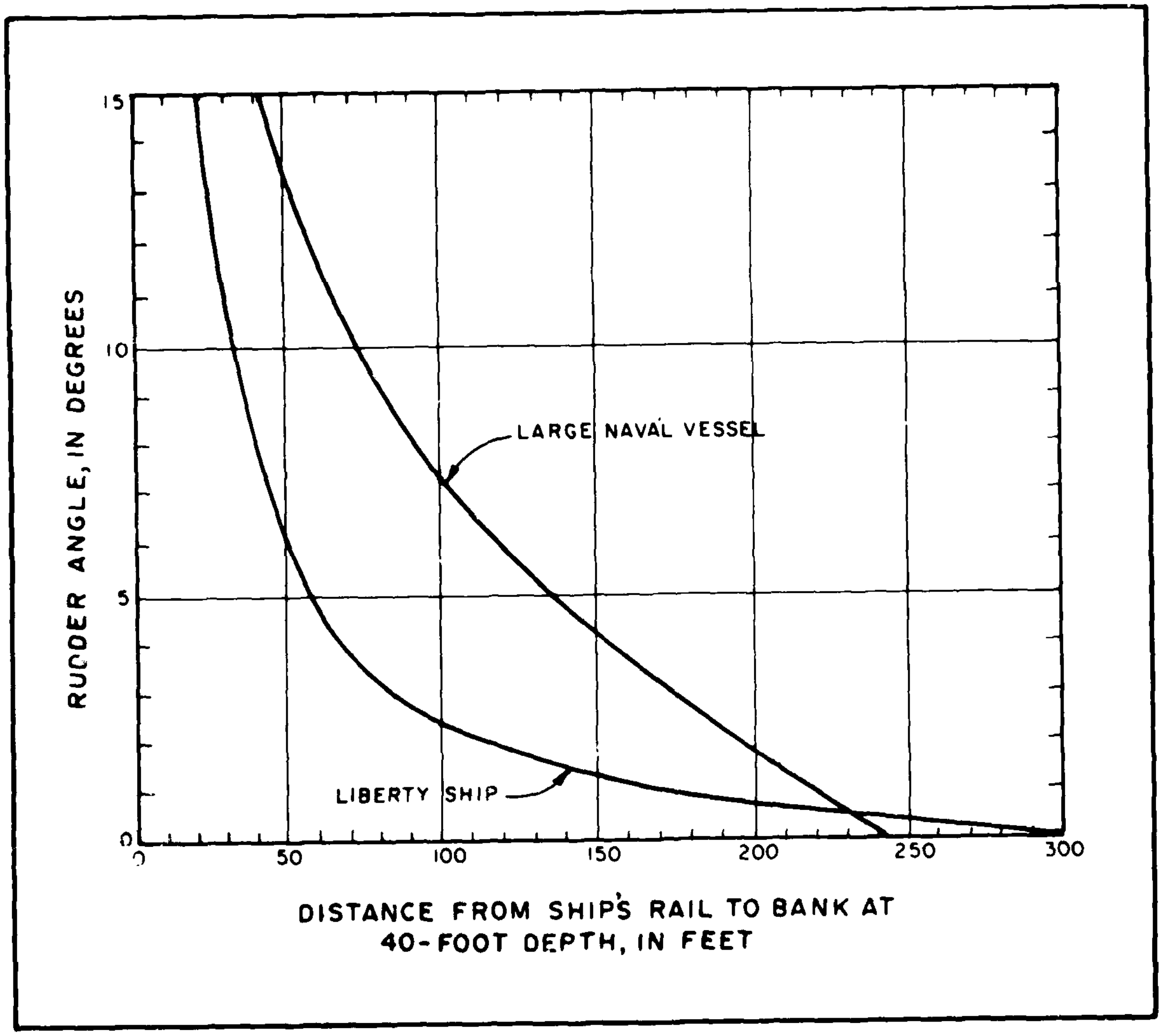


FIGURE 28
Bank Clearance Versus Rudder Angle

For sustained travel by a naval vessel in a restricted channel, a 5-degree rudder angle is a desired maximum.

In addition to rudder-angle and vessel-handling criteria, overall vessel safety must be considered in determining bank-clearance distance. In an open channel, the markings of the channel limits may not be as fully defined as in a restricted channel. This can be compounded in times of poor visibility. Similarly, where there exists a high damage probability for grounding, as in the case of an underwater rock ledge, additional bank-clearance margins should be considered. Extra allowance should also be made where the channel is subject to siltation from the side slopes. Under conditions such as those mentioned above, the minimum desired bank clearance for design purposes should be equal to the beam of the largest vessel frequenting the harbor. For open channels with steeper than 1-on-3 side slopes, this minimum clearance should be 1.2 times the beam. Examples of existing interior channels are given in Table 9.

TABLE 9
Examples of Existing Interior Channels

Harbor	Width (ft)	Depth (ft)	Remarks
Baltimore-Fort McHenry Channel	400	35	Open-type channel
Norfolk--Thimble Shoal	1,540	45	Open-type channel
Charleston--Naval Weapons Annex, Kingston	500	35	Riverine, open-type channel
Columbia River--Astoria Range	600	40	Riverine, open-type channel
Oakland--Bar Channel	300	35	Open-type channel
San Pablo Bay--Pinole Shoal	600	35	Open-type channel
Long Beach	1,000	34	Restricted-type channel
San Diego	700	41	Open-type channel

EXAMPLE PROBLEM 5

Given: The widest vessel to transit a restricted interior channel is a guided missile cruiser.

Find: The required interior channel width to allow one ship to transit the channel at a time.

Solution: From Table 4 for a guided missile cruiser, designation CHN 36, B = 61 feet.

In order to estimate the total interior channel width, w, use the largest dimensioning as shown in Figure 27 for a restricted channel:

EXAMPLE PROBLEM 5 (Continued)

$$w = \text{bank clearance} + \text{ship lane} + \text{bank clearance}$$

$$w = 1.5B + 2.0B + 1.5B$$

$$w = (1.5)(61) + (2.0)(61) + (1.5)(61)$$

$$w = 91.5 + 122 + 91.5$$

$$w = 305 \text{ feet}$$

b. Channel Bends. Bends in channels should be avoided if possible. If channel bends are unavoidable, the channel should be widened to account for the fact that the path of a ship in a bend is wider than in straight sections. The criteria for designing channel bends depend upon:

(1) the angle of deflection, defined as the angle between the two straight sections of the channel;
(2) the speed of travel of and the properties of the vessel;
(3) the characteristics of the channel;
(4) the visibility, obstructions, and aids to navigation in the vicinity of the bend; and
(5) human elements.

(1) Open-Type Channels. A change from one direction of the channel into another can be accomplished for an open-type channel without the introduction of a curved bend, provided the vessels encountering the bend are highly maneuverable and the change in direction is not too large. Such a bend is called a straight-line bend and is shown with alternative methods of widening the channel in Figure 29.

(2) Restricted-Type Channels. If the bend occurs in a restricted-type channel, the change of direction is large, or the maneuvering characteristics of the vessels frequently using the channel are poor, introduction of a curve in the channel becomes necessary. In designing a channel curve, the critical factor is determination of the radius of the curve. The criteria upon which the radius, R, is based are the length, l_v, of the ship entering the channel and the angle of deflection, α, of the channel bend. The general rules governing determination of the radius are as follows:

(1) Minimum R = 3,000 feet for a ship under its own power.
(2) R = 1,200 to 2,000 feet for tug assistance.
(3) If the angle of deflection is greater than 10 degrees, the curve should be widened at the inside curve.
(4) The tangent length between consecutive curves where there are no obstructions should be 1,000 feet or 2 l_v (where l_v = length of the largest ship using the channel), whichever is larger.
(5) Reverse curves should not be used except in special situations.

Rules governing the radius, based on angle of deflection, are:

(1) $R = 3\ l_v$ minimum for $\alpha < 25^\circ$.
(2) $R = 5\ l_v$ minimum for $25^\circ < \alpha < 35^\circ$
(3) $R = 10\ l_v$ minimum for $\alpha > 35^\circ$

Rules governing the radius, based on vessel length, are:

(1) R = 4,000-foot minimum for $l_v < 500$ feet
(2) R = 7,000-foot minimum for $l_v = 500$ feet
(3) R = 7,000 to 10,000 feet for 500 feet $< l_v <$ 700 ft

The radius of the curve must fulfill the above criteria. Once R has been determined, the channel-bend geometry must be determined. This consists of widening the channel at the bend and providing a smooth transition from the straight portions of the channel through the curve. This can be done in several ways, as shown in Figures 30 to 34. The entire amount of widening in the channel could be added to the inside of the channel, as shown with curved transitions in Figure 31 and straight transitions in Figure 32. The widening could also be split on the inside and outside of the curves equally, as shown in Figure 33, or unequally, as shown in Figure 34. For final design, an investigation considering local conditions and dredging costs is required to optimize bend geometry. If widening the channel cannot be achieved due to existing soil conditions or structures, tugs must be used to assist ships.

EXAMPLE PROBLEM 6

Given: It is necessary to construct a bend in a restricted channel of 400-foot width such that a change in direction of 50 degrees is achieved. The largest vessel to encounter the bend is an amphibious command ship (l_v = 620 feet). A structure on the outside curve precludes any widening of that side of the channel.

Find: Determine the channel dimensions through the bend.

Solution: The channel is the restricted type; therefore, it is assumed that the channel bend is curved.

w = 400 feet

l_v = 620 feet

$\alpha = 50^\circ$

On the basis of angle of deflection:

$R = 10\ l_v$ for $\alpha > 35^\circ$

THEREFORE: $R = (10)(620) = 6{,}200$ feet

EXAMPLE PROBLEM 6 (Continued)

On the basis of vessel length:

R = 7,000 to 10,000 feet for 500 feet < l_v < 700 feet.

For the purposes of this example, use:

R = 8,000 feet

Assuming it is too expensive to construct the channel with curved transitions and taking into consideration the fact that the outside curve cannot be widened, the curve in Figure 32 is chosen. Using known values of R, l_v, and w, the curve is drawn to dimensions shown in Figure 35.

c. Entrance Channels.

(1) Entrance Channel Widths.

(a) Breakwater gaps. In practice, vessels transit gaps between breakwaters one at a time. Observations reveal that in practice a second vessel will normally stand off and allow the first vessel to complete its passage through the gap to and from protected water. A minimum entrance gap width of 0.8 to 1.0 times the length of the vessel appears to be adequate for most sea conditions.

(b) Channel entrances. Vessels require more room to maneuver in and out of channels leading to protected harbor waters. Therefore, prescribed widths for interior channels must be increased to allow for additional channel width at the entrance. By utilizing vessel beam and its length, the increase in vessel beam can be approximated by the following equation:

$$B' = B + l_v \tan \theta \qquad (3\text{-}1)$$

WHERE: B' = adjusted vessel beam

B = vessel beam

l_v = vessel length

θ = yaw angle

Yaw angle should be assumed to range from 5 to 15 degrees, depending upon entrance exposure. The adjusted vessel width, B', is used in ship-lane width determinations with ratio factors similar to those used in interior-channel design. (See Figure 27.)

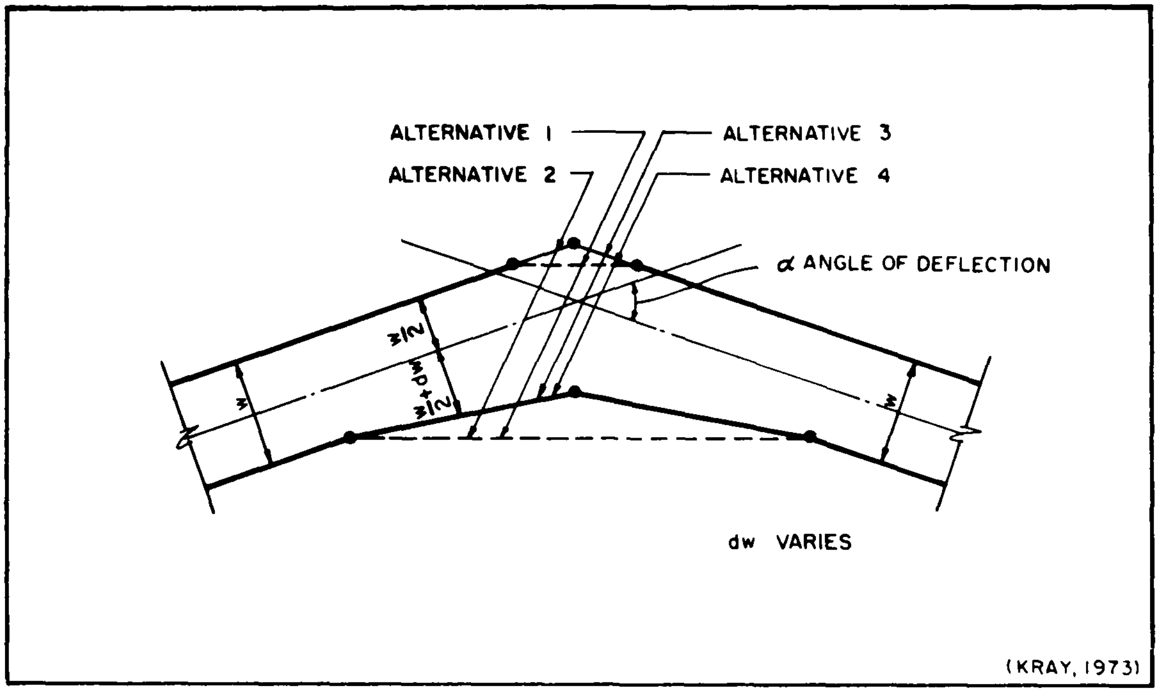


FIGURE 29
Straight-Line Bend--Alternative Methods of Widening Open-Type Channel

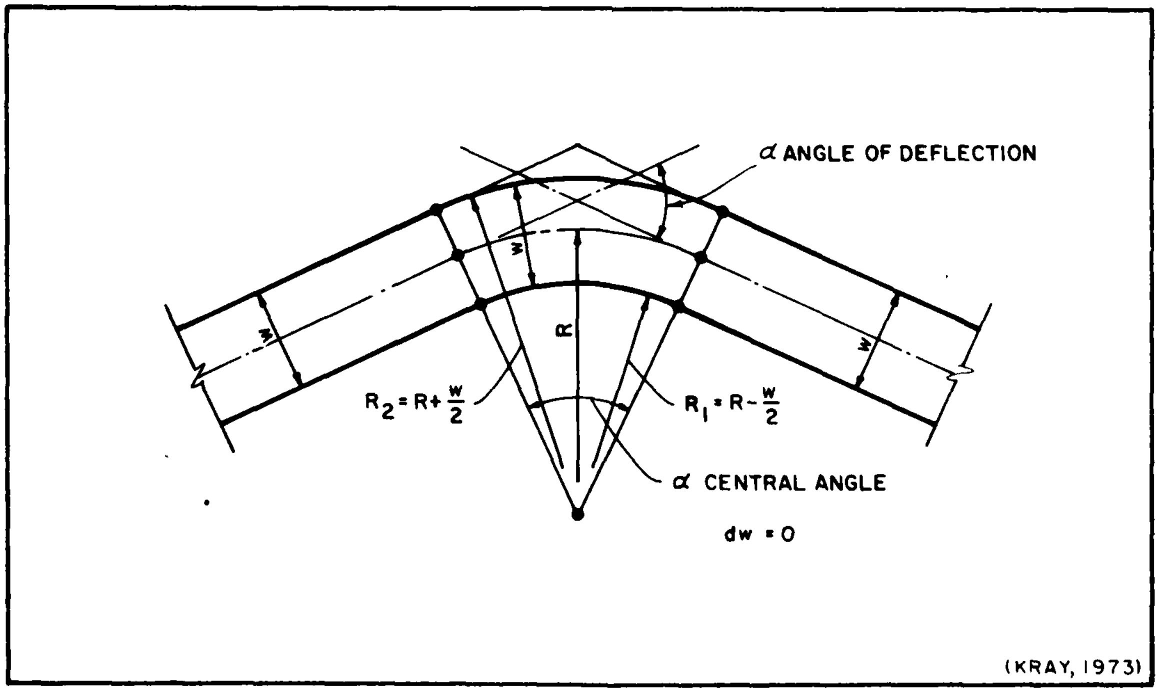


FIGURE 30
Parallel Constant-Width Turn in Channel

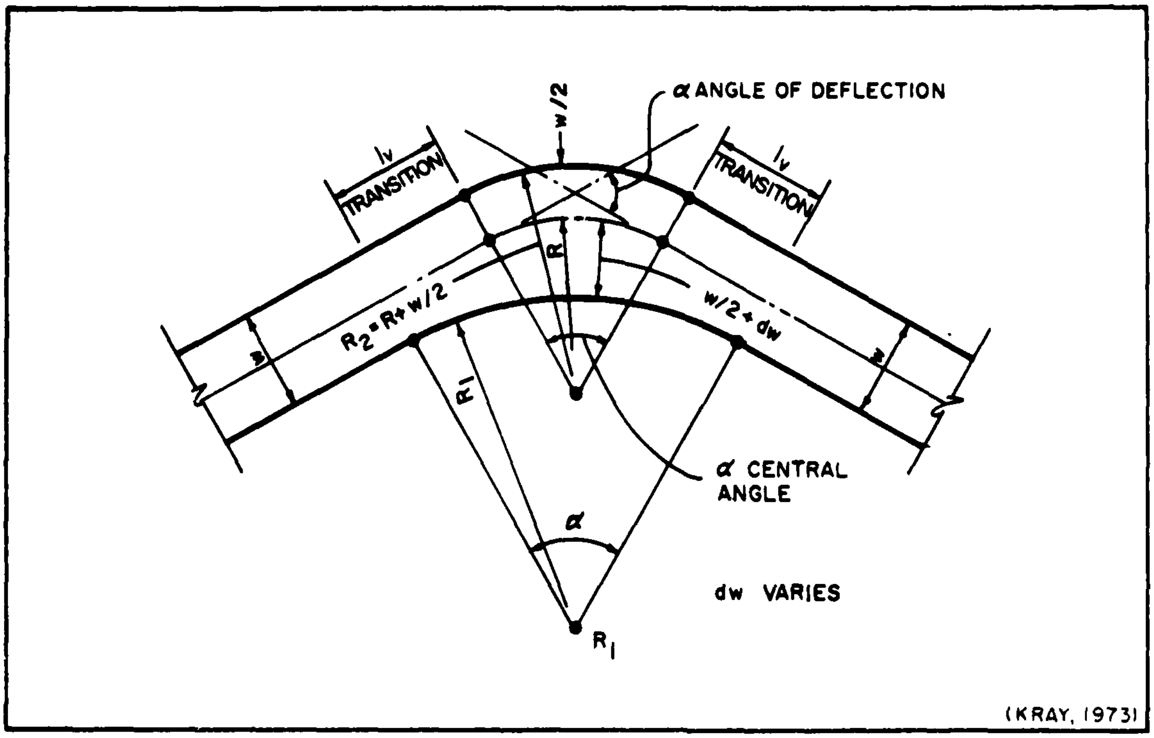


FIGURE 31
Unsymmetrically Widened Turn With Curved Transitions

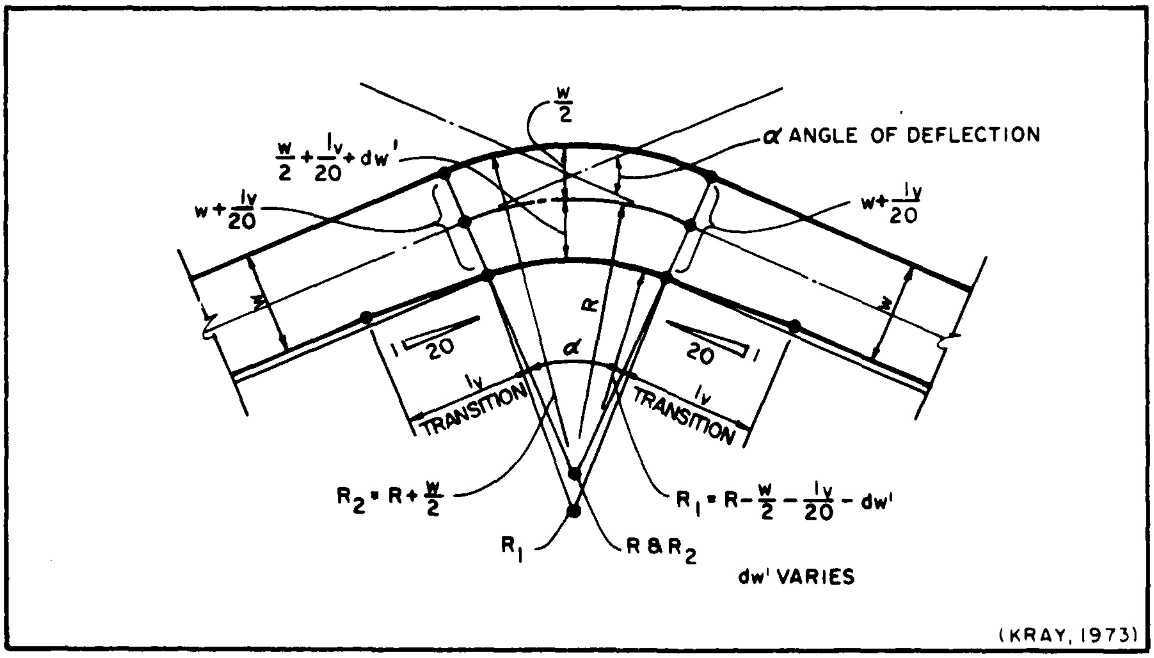


FIGURE 32
Unsymmetrically Widened Turn With Straight Transitions

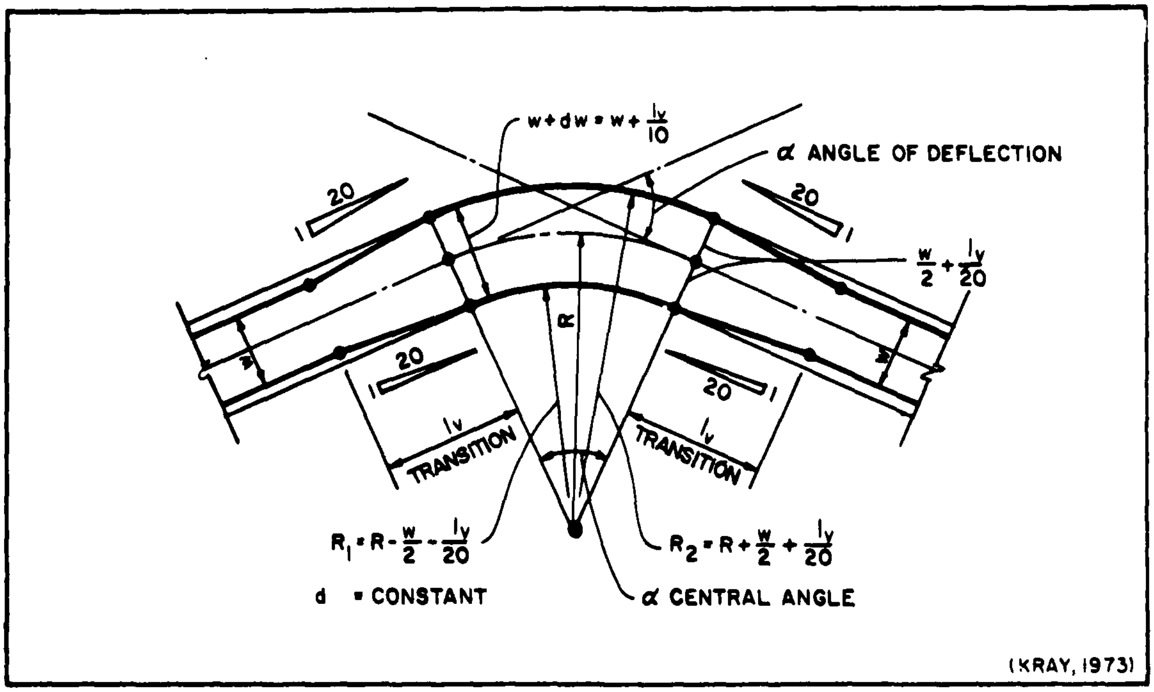


FIGURE 33
Parallel Widened Turn in Channel

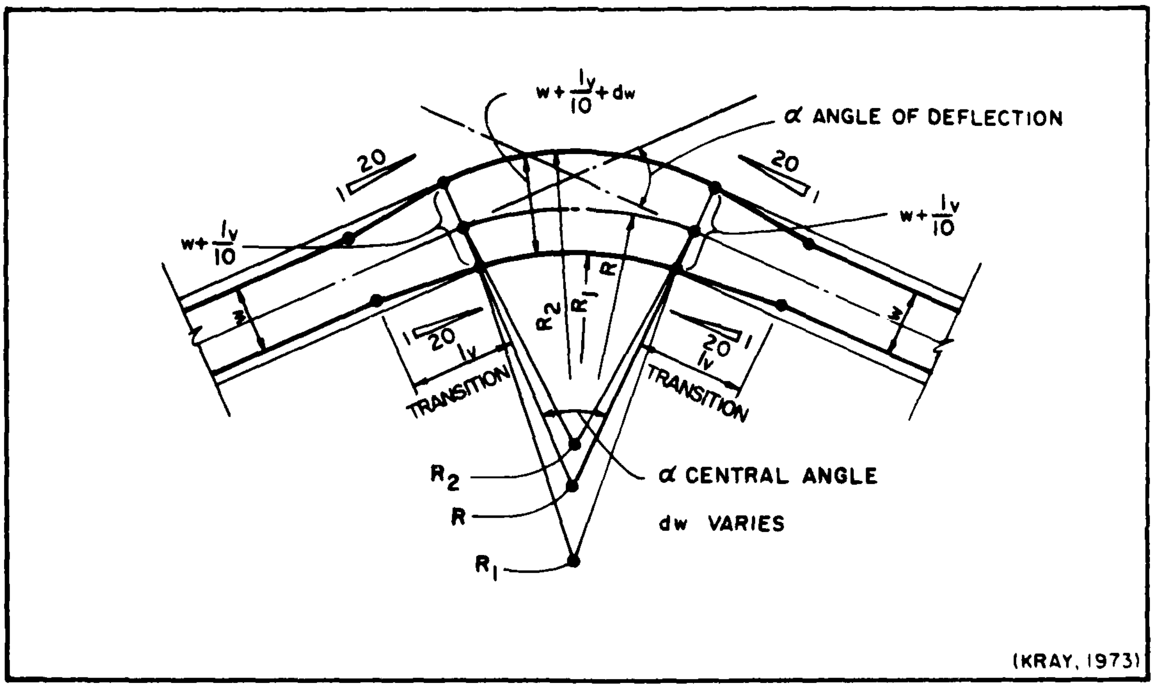


FIGURE 34
Symmetrically Widened Turn With Straight Transitions

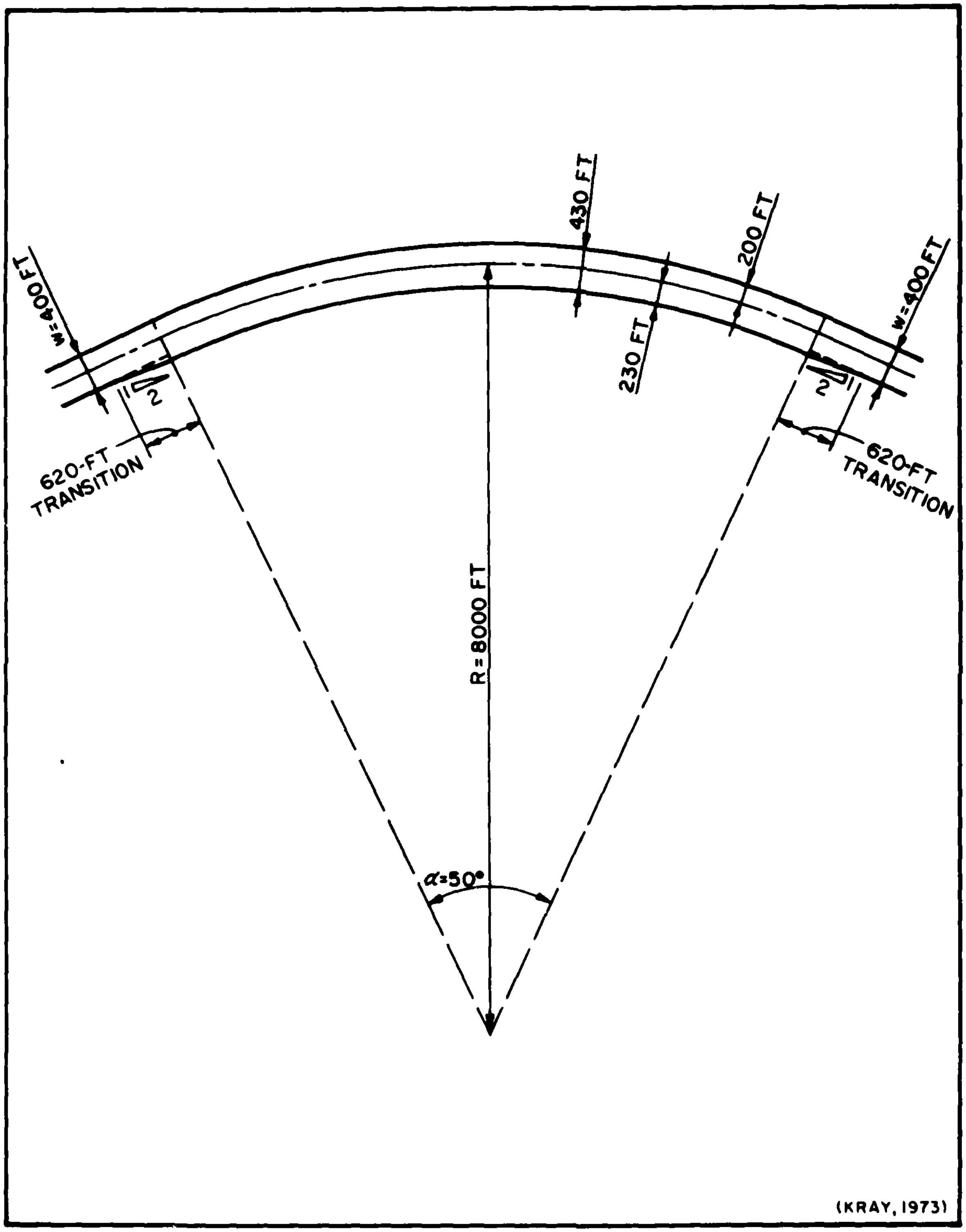


FIGURE 35
Solution to Example Problem

EXAMPLE PROBLEM 7

Given: A harbor is to be constructed to accommodate naval vessels. The largest vessel to be accommodated by the harbor is a destroyer.

Find: The required entrance-channel width of a restricted channel to allow one destroyer to enter the harbor at a time.

Solution: Assume a yaw angle of 10 degrees. From Table 4 for a destroyer, l_v = 564 feet, B = 55 feet.

$$B' = B + l_v \tan \theta$$

$$B' = 55 + 564 \tan 10^{\circ}$$

$$B' = 55 + (564)(0.1763) = 55 + 99.43 = 154.43$$

In order to estimate the total entrance-channel width, w, assume the maximum dimensioning as shown in Figure 27 for a restricted channel:

$$w = 1.5\ B' + 2.0\ B' + 1.5\ B'$$

$$w = (1.5)(154.43) + (2.0)(154.43) + (1.5)(154.43)$$

$$w = 231.64 + 308.86 + 231.64$$

$$w = 772.14 \text{ feet}$$

(2) Entrance Channel Length. In order to safely negotiate the entrance channel, vessels normally must maintain a higher rate of speed than is required or permitted within a harbor. Thus, the entrance channel should be of a length sufficient to allow vessels to reduce velocity before entering the harbor proper. For vessels entering with speeds in the range of 5 to 10 knots, allow one vessel length of slowing distance per knot of entering speed between the entrance and the turning basin. For medium-sized vessels with no tug-assisted speed arrestment, a minimum of 3,500 feet should be provided.

3. BERTHS AND BERTHING BASINS. Figure 36 shows types of berth arrangements. Table 10 lists factors affecting the selection of the location of berthing basins. A rule of thumb is that the wave height in the berthing basin should not exceed 2 feet for comfortable berthing, but in no case shall the wave height exceed 4 feet.

a. Quayage Required. Quayage requirements of piers and wharves for the various classes of vessel may be estimated from tabulated data in DM-25. Consult with the using agency for data on the maximum number of ships of various classes (including lighters) to be simultaneously accommodated.

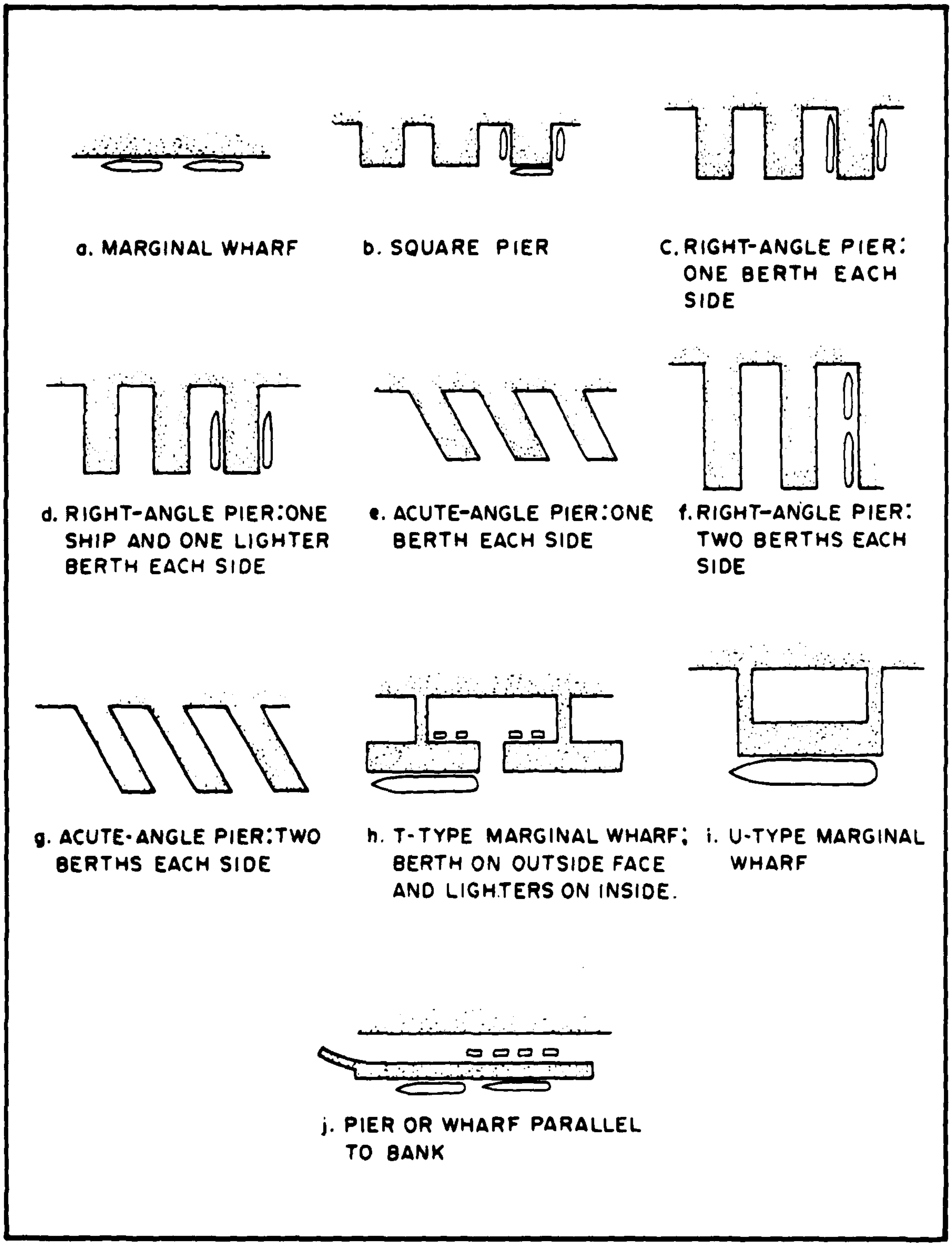


FIGURE 36
Types of Berthing Layouts

TABLE 10
Factors Affecting Location of Berthing Basins

Factor	Requirement and Comment
Protection	Locate berthing basins in harbor areas which are best protected from wind and wave disturbances and/or in areas remote from the disturbances incident upon the harbor entrance.
Orientation	Orient berths for ease of navigation to and from entrance and channel.
Offshore area	Provide sufficient area offshore of berths for turning ships, preferably without use of tugs.
Quayage adequacy	Adequate quayage shall be provided for expected traffic.
Expansion	Provide area for future expansion.
Fouling and borers	Where possible, locate berthing basin in area of harbor with minimum fouling conditions and minimum incidence of marine borers. Elliott, Tressler, and Meyers (1952) indicate some advantages for locations in the ebb side of an estuary harbor. The ebb side of an estuary in the Northern Hemisphere is the right side looking seaward.
Foundations	Where feasible, locate in area of favorable subsoil conditions, in order to minimize cost of berthing structures.
Supporting shore facilities	Locate supporting shore facilities in proximity to their respective berths. Adequate space and access for upland road and railroad facilities are essential. In general, it is desirable to have a wide marginal street at the inshore ends of the piers or wharves and a wide street on the pier axis. Annual capacity per terminal is based on commercial throughput values obtained from Hockney (1979).

Single Berth Terminal by Cargo Class	Cargo Throughput (tons per year)
Break-bulk general	66,000
Neo-bulk general cargo	130,000
Containerized general cargo	360,000
Dry bulk--silo storage	1,000,000
Dry bulk--open storage--low density	500,000
Dry bulk--open storage--high density	1,000,000
Liquid bulk--other than petroleum	90,000
Petroleum bulk--up to 50,000 dwt ships	1,500,000
Petroleum bulk--30,000 to 200,000 dwt ships	6,000,000

b. Arrangement of Berths.

(1) Selection. The arrangement of berths must fit the proposed site without encroaching on pierhead or bulkhead lines. For steeply sloping subgrades, the berths must fit within the depth contour below which the driving of piles is impractical. In selecting the berthing arrangement, consider the factors relating to economics and utility (see Table 11).

(2) Relative Berthing Capacities. Table 12 shows linear feet of berthing space per 1,000 feet of shore front.

c. Size and Depth of Basin and Berths. For the general depth requirements for the basin, see Subsection 6, DEPTH REQUIREMENTS, of Section 2.

(1) Berthing Area. For berthing-area requirements for piers, see Table 13. For ships berthed at marginal wharves or quay walls, provide twice the total area requirement shown in Table 13 for pier berthing. Allow additional area within the harbor limits for channels, special berths, turning basins, and other facilities.

(2) Depth. Except where heavy silting conditions require greater depth at individual berths at low water, the depth should equal the maximum loaded draft of the largest vessel to be accommodated plus 10 percent. On mud or silt bottoms, consider increasing depth requirements if investigation indicates probable fouling of condensers on the vessel due to the proximity of the mudline to intake pipes of the condenser system. Where vessels to be accommodated are not specifically known, the values in Table 14 may be used.

(3) Clear Width of Slips Between Piers (See DM-25.1.)

(4) Length of Berth. (See DM-25.1.)

(5) Width of Piers.

(a) Square pier systems. Width should be capable of berthing the longest expected ship. The net area of the pier should be three times that required for a single berth terminal.

(b) Finger pier system. Pier width varies. Width requirements may be estimated from data in DM-25.1.

(6) Special Berths.

(a) Fueling vessels. Berths should be at least 500 feet from adjacent berths.

(b) Explosives. Berths should be separated in accordance with the quantity-distance relationships established in DOD 5154.4S and NAVSEA OP 5.

TABLE 11
Selection Factors for Berthing Arrangements

Berthing System	Advantages	Disadvantages
Marginal wharf (figure 36a)	Solid fill supports deck loads without expensive framing. Accessibility of entire upshore area for working space, storage space, laydown operations, and traffic circulation adds to the utility of the wharf as compared to pier or offshore wharf systems. Permits utilization of surplus fill material. Suitable for sites where pier cannot be projected out from shore and where dredging of a recessed basin for piers would be expensive. Also suitable where the navigation channel is too narrow to permit maneuvering into finger piers.	Costs per berth greater than for pier systems. Ratio of berthing space to length of waterfront is low. Berthing length is limited to length of face of wharf, unless mooring dolphins are used to extend usable length.
Square pier (figure 36b)	Solid fill supports deck loads without expensive framing. Upshore area is accessible for storage and traffic circulation. Side-berth accommodations add to linear feet of berthing accommodations. Permits utilization of surplus fill material.	Economy depends on availability of inexpensive fill. The requirements for fill or piling are great compared to the usable space provided on the deck.
Rectangular pier and slip (figures 36c, 36d, and 36f)....	Length of accommodation for a given length of shoreline is great. In general, this system has the lowest relative cost per berth.	In some bottom formations, any considerable later dredging of slips may be hazardous. Space between slips is limited, and adds to the density of navigation traffic. Reduces width of navigation channel.

TABLE 11
Selection Factors for Berthing Arrangements (Continued)

Berthing System	Advantages	Disadvantages
Rectangular pier and slip (continued)		Cargo handling is restricted unless pier has at least 6 acres per berth.
Angle pier and slip (figures 36e and 36g)	Layout is advantageous compared to rectangular pier-and-slip system where navigation channel is too narrow for perpendicular pier layout. Currents or prevailing winds may also dictate the use of angle piers.	Construction is more difficult and expensive than that for rectangular pier-and-slip system. Corners of the pier are waste space where cargo-handling equipment cannot work.
Offshore marginal wharves (figures 36h, 36i, and 36j) ...	Layout adaptable to many types of construction methods, including floating wharfage. Moorings for shallow-draft craft may be provided along the sides of the causeway. When multiple causeways are used, a movable section can be provided to give access to space between causeways. Suitable along rocky shores. Suitable where water of adequate depth is located at large distance offshore.	When a single causeway is used, craft along the causeway create loading and unloading and traffic problems. Usually requires separate moorings, supported by the wharf structure, because a relatively large area of the wharf structure is not tied to shore anchorages.
Floating wharves .	Floating wharves can be moored in water too deep for pile driving. Pontoon or prefabricated sections can be used. Equipment can be quickly assembled, moved, and replaced.	Maintenance is high. (Maintenance of steel floating wharves is higher than that of concrete floating wharves.) Not suitable for heavy craft nor in exposed locations without heavy anchorage requirements. Difficult to maintain alinement in heavy tide range. Restricted cargo-handling capability.

TABLE 12
Linear Feet Of Berthing Space Per 1,000 Feet Of Shore Front

Type of Layout	Freighter[1]	Lighter[1]	Total[1]
Marginal wharf	1,000	.....	1,000
Square pier	2,143	.....	2,143
Right-angle pier for one freighter on each side	3,120	313	3,433
Right-angle pier for one freighter plus one lighter on each side	3,120	1,250	4,370
Acute-angle pier for one freighter on each side	2,690	270	2,960
Right-angle pier for two freighters on each side	4,160	208	4,368
Acute-angle pier for two freighters on each side	3,600	180	3,780
T-type marginal wharf for freighter on outside face and lighters on inside face	770	[2]1,380	[2]2,150
U-type marginal wharf	1,000 or less	.....	1,000 or less
Pier or wharf parallel to bank	2,000	.....	2,000

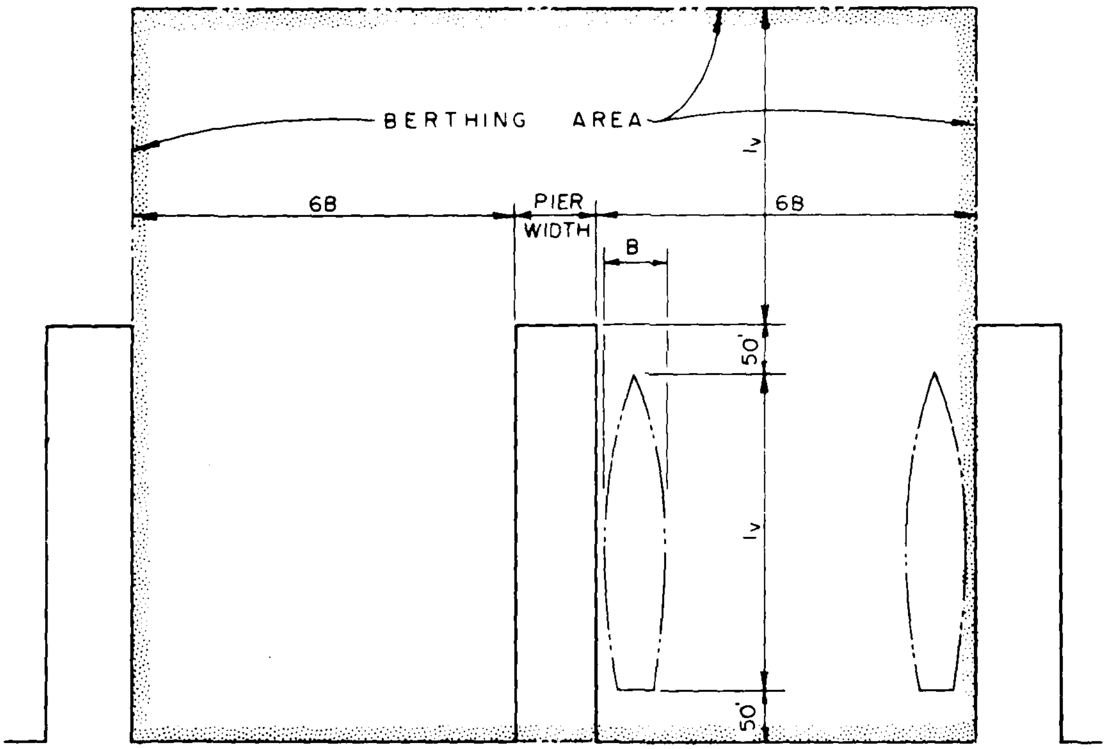
[1]These figures are for purposes of comparison only.

[2]1,682 ft and 2,452 feet, respectively, if traffic conditions are such that lighters can be worked along the faces of the causeway.

TABLE 13

Approximate Berthing-Area Requirements for Single-Berth Piers[1]

Class of Ship	Sizes of Piers (ft)	Spacing of Piers (ft)	Total Area Required in Harbor (acres)
Submarines	60 x 520	[2]330	[2]16
Destroyers	80 x 670	330	21
Auxiliaries	80 x 900	640	53
Aircraft carrier ...	100 x 1,250	780	88



[1]Area = $[2\, l_v + (2)(50^*)][^{2}12B + \text{pier width}]$. (See diagram.) Values for l_v, B, and pier width were chosen from DM-25.1 for purposes of this table.

[2]At submarine slips, pier spacing should be increased by at least four vessel beams.

*100 feet for aircraft carrier

TABLE 14
Berthing Depths for Typical Naval Vessels

Vessel	Depth[1] (ft)
Small boats	8 to 15
Minesweepers	18
Landing ships	24
Frigates	30
Tenders, cargo, and transport ships	34
Guided missile cruisers, destroyers, and medium submarines	36
Carriers and fast combat support ships[2]	45

[1]These depths are referenced to mean low water (MLW) or mean lower low water (MLLW) statistics for the area under study.

[2]See note 5, Table 4.

d. Demarcation.

(1) Navigation Lights. These lights should be provided at offshore ends of piers and other projecting structures. (See Section 4, AIDS TO NAVIGATION, of this manual for criteria.)

(2) Floodlighting. For floodlighting see DM-25.2.

(3) Aids to Berthing. For station markings and their location see DM-25.1.

4. TURNING BASINS. Where space is available, provide turning basins to minimize the use of tugs. Where space is restricted, tugs may be used for turning vessels and turning basins thereby eliminated.

a. Location. The following requirements must be met:

(1) Locate one turning basin at the head of navigation.
(2) Locate a second just inside the breakwater.
(3) Where especially heavy traffic is anticipated, provide intermediate basins to reduce congestion and save time.
(4) Where feasible, use an area of the harbor, which in its natural state, has the required size and depth.
(5) A turning basin is frequently desirable at the entrance to drydocks or at the interior or landward end of long piers or wharves providing multiple-length berthing.

b. Size and Form. As a rule of thumb, consider that a vessel can be turned comfortably in a radius of twice the vessel length, or, where ease of maneuver is not important, in a radius equal to the vessel length. For shorter turning radii, the vessel must be assisted by tugs. With tug assistance, where wind and current effects are not critical, naval vessels can be

turned in a circle with a diameter of 1.5 times the vessel length. (See Table 15 for dimensions of typical existing turning basins.)

TABLE 15
Dimensions of Typical Existing Turning Basins

Location	Depth Below MLW (ft)	Dimensions (ft)	Area (acres)
Port Arthur, East Turning Basin	36	420 x 1,800	17.35
Port Arthur, West Turning Basin	36	600 x 1,700	18.12
Brazosport Turning Basin	32	700 x 700	11.25
Norfolk Harbor, Virginia South Branch Project	35	600 x 600	8.25
Wilmington Harbor	32	1,000 x 800	18.36
Miami Harbor	30	1,350 x 1,400	20.43
Tampa Harbor	30	700 x 1,200	19.38
Alameda Naval Air Station	42	4,000 x 2,500	230.00
San Diego Harbor	40	2,400 x 3,000	165.29

5. ANCHORAGE BASINS.

a. Siting Factors. Table 16 lists factors affecting location, size, and depth of anchorage basins.

(1) Free-Swinging Moorings and Standard Fleet Moorings. For the diameter of the swing circle and the area requirements per vessel, see Tables 17 and 18. For size of berth for floating drydocks, spread-moored, see Table 19. Additional area allowance should be made for maneuvering vessels into and out of berths and for waste space between adjacent berths.

b. Demarcation. Anchorage areas should be marked. (See Section 4, AIDS TO NAVIGATION.)

c. Dangerous Cargo.

(1) Tankers. Anchorages for tankers and similar vessels should

TABLE 16
Factors Affecting Location, Size, and Depth of Anchorage Basins

Consideration	Factor	Requirement and Comment
Location	Isolation	Locate near entrance, away from channels, out of traffic, and in shelter. The area should be isolated, insofar as possible, from attack by surface or subsurface craft.
	Depth	Locate in area of sufficient natural depth to avoid dredging.
	Currents	Area should be free from strong currents.
	Accessibility of shore facilities	The area should be accessible to fresh water, fuel, and fleet recreation facilities. Shore facilities shall be provided to accommodate liberty parties, mail, light freight, and baggage.
	Foundation conditions	Where possible, locate over a bottom of loose sand or gravel, clay, or soft coral. Avoid locations where the bottom consists of rock, hard gravel, deep mud, and deep silt.
	Subaqueous structures	Anchorage areas should be free of cables and pipelines and cleared of wrecks and obstructions.
	Expansion	Leave provision for future expansion.
Size and depth	....	Size of individual free-swinging moorings and of spread moorings for floating drydocks are contained in Tables 17, 18, and 19. Use free-swinging moorings where available area will permit. Where available area is limited, use fixed moorings or moorings in which the swing of the vessel is restricted. Various types of restricted moorings are described in DM-26.5.

be at least 500 feet from adjacent berths, and located so that prevailing winds and currents carry spillage away from general anchorage and berthing areas.

(2) Explosives. Anchorages for vessels carrying explosives should be separated in accordance with quantity-distance relationships established in DOD 5154.4S and NAVSEA OP 5.

6. NEW FACILITIES IN EXISTING HARBORS. Where new facilities are to be developed in an existing port, these facilities are subject to the same criteria as the development of a new port. For information concerning permits and controlling agencies, see Section 2.3 of this manual.

7. SUBMARINE FACILITY SPECIAL REQUIREMENTS.

a. Special Considerations. Harbors designed to accommodate naval submarines of the various classes require special attention during the planning stage. Since surfaced submarines are relatively unwieldy deep-draft vessels with low freeboards, channels and other water areas to be used by submarines must be wide and deep enough for safe maneuvering.

b. Entrances and Channels. Surfaced submarines are susceptible to wave action, surge, and currents. Submarines require still water not only during docking and mooring operations, but especially while negotiating the entrance and channels. Where moorings are located in estuaries and rivers subject to strong currents, or where entrances are subject to moderate to strong wave action, protection in the form of jetties or breakwaters should be provided.

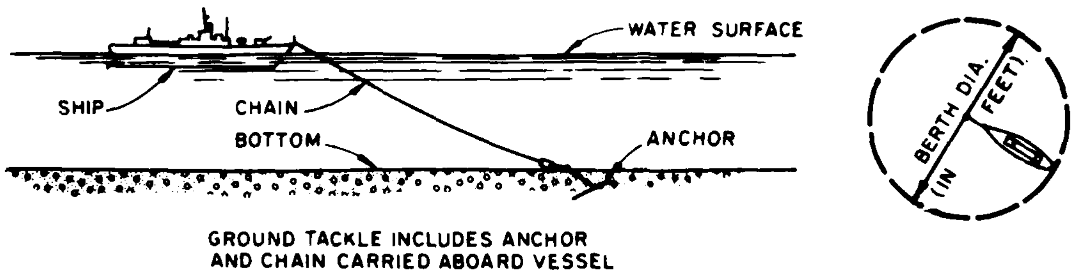
c. Mooring and Docking.

(1) Moorings. Because of its "barrel" cross section, a submarine's beam underwater exceeds the width of its above-water superstructure. Thus, to safely moor submarines, an underwater fendering system is mandatory. Such "deep-draft separators" function as camels, with the difference being that the apparatus extends deep enough to buffer the widest point of the vessel. The depth required depends upon the specific submarine. For example, if the draft of the submarine is 33 feet, the separator must extend a minimum of 18 feet below the surface. Separators are normally between 30 and 50 feet in length. Facilities for docking submarines and the design of deep-draft separators are described in DM-25.1. However, it should be remembered when designing harbors to accommodate submarines that ample storage area is needed for deep-draft separators not in use. Further, consideration should be given to water-area docking or mooring requirements for small craft servicing deep-draft separators and other support structures.

(2) Piers and Wharves. Special requirements for the design of piers and wharves to accommodate submarines are contained in DM-25.1. It should be noted that in the absence of tug assist, the water approaches to submarine docking facilities should be designed to accommodate the largest vessel anticipated. Table 20 lists typical submarine dimensions for preliminary design purposes.

TABLE 17

Diameter of Berth, in Feet, Using Ship's Anchor and Chain[1]



Overall Vessel Length, in Feet	100	200	300	400	500	600
Depth of Water at MLLW (ft)						
10	495	705	900	1,095	.....	.....
20	615	810	1,020	1,215	1,410	1,620
30	735	930	1,140	1,335	1,530	1,740
40	855	1,050	1,260	1,455	1,650	1,860
50	975	1,170	1,365	1,575	1,770	1,965
60	1,095	1,275	1,485	1,695	1,890	2,085
70	1,170	1,320	1,605	1,815	2,010	2,205
80	1,230	1,380	1,710	1,920	2,130	2,310
90	1,275	1,425	1,770	2,010	2,190	2,370
100	1,335	1,470	1,815	2,055	2,250	2,415
110	1,380	1,515	1,860	2,100	2,295	2,460
120	1,425	1,545	1,905	2,145	2,340	2,505
130	1,470	1,590	1,950	2,205	2,385	2,550
140	1,515	1,635	1,995	2,235	2,430	2,595
150	1,545	1,665	2,040	2,280	2,475	2,625
160	1,590	1,710	2,085	2,325	2,505	2,670
170	1,620	1,740	2,130	2,370	2,550	2,700
180	1,665	1,770	2,160	2,400	2,595	2,745
190	1,695	1,800	2,205	2,445	2,625	2,775
200	1,740	1,845	2,235	2,490	2,670	2,820

TABLE 17

Diameter of Berth, in Feet, Using Ship's Anchor and Chain[1] (Continued)

Overall Vessel Length, in Feet	700	800	900	1,000	1,100	1,200
Depth of Water at MLLW (ft)						
10	.....	.....	.....	.....	.....	.....
20	.....	.....	.....	.....	.....	.....
30	1,935	2,130	2,340	.....	.....	.....
40	2,955	2,250	2,460	2,655	2,850	3,060
50	2,175	2,370	2,655	2,775	2,970	3,165
60	2,295	2,490	2,685	2,895	3,060	3,285
70	2,415	2,610	2,805	3,015	3,210	3,405
80	2,505	2,700	2,925	3,120	3,255	3,540
90	2,550	2,745	2,970	3,165	3,300	3,585
100	2,610	2,790	3,015	3,210	3,390	3,630
110	2,655	2,835	3,060	3,255	3,435	3,675
120	2,700	2,880	3,105	3,285	3,480	3,720
130	2,730	2,910	3,135	3,330	3,525	3,765
140	2,775	2,955	3,180	3,375	3,555	3,795
150	2,820	3,000	3,225	3,405	3,600	3,840
160	2,850	3,030	3,255	3,450	3,630	3,870
170	2,895	3,075	3,300	3,480	3,660	3,915
180	2,925	3,105	3,330	3,510	3,705	3,945
190	2,955	3,135	3,360	3,540	3,735	3,975
200	3,000	3,165	3,405	3,585	3,765	4,005

[1] For shallower water depths, the swing radii implied by this table are based on the following assumptions:

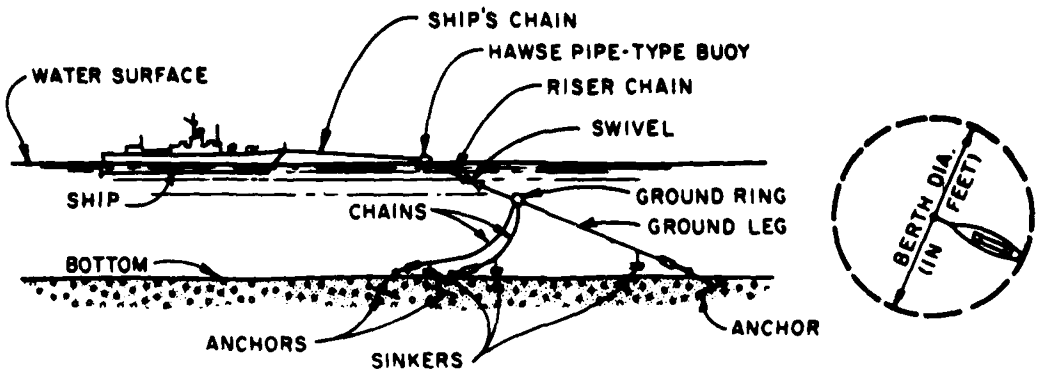
(a) Scope = 6 x depth
(b) Anchor rode has no sag
(c) Allowance for anchor drag = 90 feet

For depths greater than about 70 feet, the 6:1 scope is excessive, and swing radii are based on the computed horizontal length of the anchor chain under heavy load. Typical ship characteristics and chain sizes have been selected for each ship-length category. Assumed load conditions are as follows:

(a) Wind speed = 50 knots
(b) Current = 4 knots, alined with wind direction
(c) Vertical projection of anchor chain = depth + height of hawse hole
(d) Vertical angle of chain at anchor = 0 degrees

TABLE 18

Diameter of Berth, in Feet, Using Standard Fleet Moorings, Riser Chain[1]



Overall Vessel Length, in Feet	100	200	300	400	500
Depth of Water at MLLW (ft)					
10	825	1,020	1,215	1,425	.....
20	840	1,035	1,245	1,440	1,635
30	855	1,065	1,260	1,455	1,655
40	885	1,080	1,275	1,485	1,680
50	900	1,095	1,305	1,500	1,695
60	915	1,125	1,320	1,515	1,725
70	945	1,140	1,335	1,545	1,740
80	960	1,155	1,365	1,560	1,755
90	975	1,185	1,380	1,575	1,785
100	1,005	1,200	1,395	1,605	1,800
110	1,020	1,215	1,425	1,620	1,815
120	1,035	1,245	1,440	1,635	1,845
130	1,065	1,260	1,455	1,665	1,860
140	1,080	1,275	1,485	1,680	1,875
150	1,095	1,305	1,500	1,695	1,905
160	1,125	1,320	1,515	1,725	1,920
170	1,140	1,335	1,545	1,740	1,935
180	1,155	1,365	1,560	1,755	1,965
190	1,185	1,380	1,575	1,785	1,980
200	1,200	1,395	1,605	1,000	1,995

TABLE 18

Diameter of Berth, in Feet, Using Standard Fleet Moorings, Riser Chain[1]

(Continued)

Overall Vessel Length, in Feet	600	700	800	900	1,000
Depth of Water at MLLW (ft)					
10	.....	.....	.....	.....	.....
20	1,845	.....	.....	.....	.....
30	1,860	2,055	.....	.....	.....
40	1,875	2,085	2,280	2,475	2,685
50	1,905	2,100	2,295	2,505	2,700
60	1,920	2,115	2,325	2,505	2,715
70	1,935	2,145	2,340	2,585	2,745
80	1,965	2,160	2,355	2,565	2,760
90	1,980	2,175	2,385	2,580	2,775
100	1,995	2,205	2,400	2,595	2,805
110	2,025	2,220	2,415	2,625	2,820
120	2,040	2,235	2,455	2,640	2,835
130	2,055	2,265	2,460	2,655	2,865
140	2,085	2,280	2,475	2,685	2,880
150	2,100	2,295	2,505	2,700	2,895
160	2,115	2,325	2,520	2,715	2,925
170	2,145	2,340	2,535	2,745	2,940
180	2,160	2,355	2,565	2,760	2,955
190	2,175	2,385	2,580	2,775	2,985
200	2,205	2,400	2,595	2,805	3,000

[1]This table is based on the following assumptions:

(a) Length of riser chain is equal to depth of water at mean high water.

(b) Ground chains are of length called for by drawings and are pulled taut when installed.

(c) Anchor drags 90 feet from initial position.

(d) 180 feet of ship's chain used between vessel and buoy.

(e) Basic formula $b = (2/3)(d + l_v + C_1)$

WHERE: b = diameter of berth, in feet

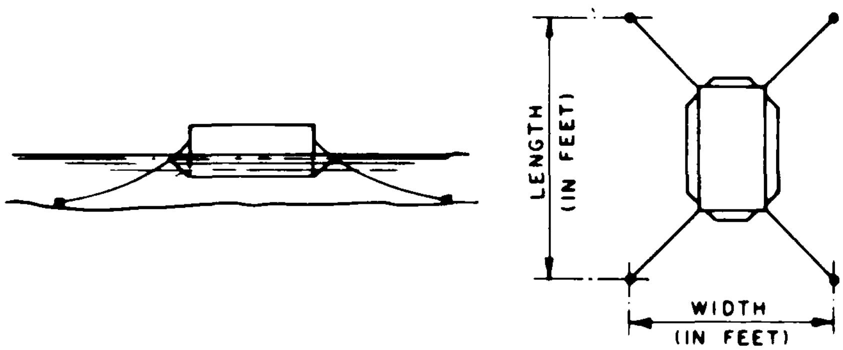
d = depth of water, in feet at MHW

l_v = length overall of vessel, in feet

C_1 = 300 feet (includes 30-foot allowance for increase in radius of berth for drop in waterline due to fall of tide, 180 feet from buoy to ship, and 90-foot allowance for drag of anchor

TABLE 19

Size of Berth, in Feet, for Floating Drydocks and Spread Moorings[1]



Depth of Water at MLLW (ft)	ARD		AFDL 2,800 T concrete		AFDB 10 sections		AFDB 9 sections	
	Width	Length	Width	Length	Width	Length	Width	Length
33	.....	.....	.....	.....	.....	.....	.....	.....
38	600	945	.....	.....	.....	.....	.....	.....
41	600	945	615	900	.....	.....	.....	.....
50	690	1,005	690	975	.....	.....	.....	.....
57	765	1,050	780	1,035	.....	.....	.....	.....
65	765	1,065	780	1,080	.....	.....	.....	.....
74	840	1,125	855	1,140	.....	.....	.....	.....
84	930	1,185	945	1,200	1,140	1,710	1,140	1,620
90	1,005	1,230	1,020	1,245	1,170	1,740	1,170	1,665
100	1,005	1,260	1,020	1,320	1,230	1,815	1,230	1,725
110	1,005	1,305	1,095	1,365	1,290	1,860	1,290	1,770
120	1,140	1,335	1,185	1,410	1,335	1,905	1,335	1,830
130	1,215	1,395	1,260	1,455	1,380	1,950	1,380	1,875
140	1,290	1,425	1,260	1,515	1,425	1,995	1,425	1,905
150	1,365	1,485	1,320	1,560	1,470	2,040	1,470	1,950
160	1,365	1,485	1,395	1,605	1,500	2,070	1,500	1,980
170	1,410	1,515	1,395	1,650	1,530	2,100	1,530	2,010
180	1,470	1,560	1,470	1,680	1,545	2,115	1,545	2,025
190	1,545	1,605	1,545	1,725	1,560	2,130	1,560	2,040
200	1,545	1,620	1,545	1,740	1,560	2,130	1,560	2,040

TABLE 19

Size of Berth, in Feet, for Floating Drydocks and Spread Moorings[1]

(Continued)

Depth of Water at MLLW (ft)	AFDB 7 sections		YFD 18,000 T		AFDL 1,000 T steel		AFDL 1,900 T steel	
	Width	Length	Width	Length	Width	Length	Width	Length
33	.....	.....	.....	.....	600	750	.....	.....
38	.....	.....	.....	.....	600	750	600	855
41	.....	.....	.....	.....	600	750	600	705
50	.....	.....	.....	.....	675	825	675	930
57	.....	.....	825	1,260	765	900	765	990
65	.....	.....	825	1,290	765	930	765	1,050
74	1,005	1,485	885	1,365	840	1,005	840	1,125
84	1,005	1,485	960	1,455	930	1,080	915	1,200
90	1,065	1,560	1,050	1,515	1,020	1,155	1,005	1,230
100	1,155	1,635	1,050	1,545	1,020	1,185	1,005	1,305
110	1,155	1,635	1,110	1,620	1,095	1,245	1,080	1,350
120	1,200	1,680	1,170	1,695	1,185	1,320	1,155	1,410
130	1,275	1,755	1,245	1,755	1,260	1,395	1,245	1,470
140	1,335	1,830	1,245	1,785	1,260	1,410	2,245	1,515
150	1,365	1,830	1,305	1,860	1,335	1,470	1,305	1,560
160	1,365	1,860	1,355	1,920	1,410	1,545	1,380	1,620
170	1,425	1,920	1,355	1,935	1,410	1,560	1,380	1,665
180	1,425	1,920	1,380	1,995	1,500	1,620	1,440	1,710
190	1,440	1,920	1,440	2,055	1,575	1,710	1,515	1,755
200	1,440	1,920	1,440	2,070	1,575	1,710	1,545	1,800

[1]The width and length of berths for floating drydocks include out to out of anchors, assuming that anchors are placed in accordance with the diagram. Berth diameter for free-swinging floating drydocks may be obtained from Tables 17 and 18; in addition to that for drydock length, allowance must be made for vessel entering dock.

TABLE 20
Submarine Dimensions[1]

Class	Length Overall (ft)	Diameter of "Barrel" (ft)	Breadth at Stern Planes (ft)
688	361	33	40
637	289	32	41

[1] Note: "Trident" class missile submarines, having much larger draft and requiring special service, are accommodated at special facilities.

8. SHIPYARD SPECIAL REQUIREMENTS.

a. Mission and Requirements. Harbors or sections of harbors designed as shipyards require special facilities and designs. Shipyard facilities consist of navigation basins, piers, drydocks, and backland. Outfitting or repair piers are generally arranged as in Figure 36c or 36f. Less commonly, where space permits, repair stations could be arranged along a marginal quay, as in Figure 36a. Drydocks may be either the floating or graving type.

The numbers and types of facilities are determined by the mission the shipyard is to serve. An important tool for these determinations is the NAVSEA computerized system for determining facility, equipment, and manpower needs for U.S. naval shipyards. The system is applicable to either new shipyard planning or to plans for major revisions to existing shipyards.

b. Waterways. The shipyard portion of the harbor requires a channel sufficiently large to accommodate the largest vessel to be served by the shipyard. The water area fronting the shipyard should be a navigable basin in which the largest vessel is capable of maneuvering to and between the repair facilities. It is essential that the shipyard have quiet water and be free of strong currents. Ships at repair are frequently in "hotel" status and short of the operating personnel needed to operate them in case currents should tear them loose from their moorings.

c. Piers. Special considerations for repair and outfitting piers include crane rails for portal cranes, railroad tracks between crane rails, and special service piping to shipside galleries or service boxes. For pier design refer to DM-25.1.

d. Drydocks. Drydocks are of two basic types: floating [illegible]. Floating drydocks may be moved from place to place and are [illegible] servicing smaller ships and submarines. A floating drydock [illegible] or anchored in a location where the water is considerably [illegible] draft of the ships it serves, and it must have access [illegible] supplies and utilities. A staging and laydown [illegible].

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required to provide operational support.

A graving drydock is a permanently placed facility dug into the embankment. Such drydocks are usually equipped with portal cranes that travel around the perimeter of the dock and are surrounded by service and laydown areas for large ship parts and equipment. Space along the quay near the drydock or other moorage and clear of vessels maneuvering into the dock is required for storage of the drydock's caisson gate. For all types of drydocks, keel blocks for the various vessels served must be stored nearby.

e. Ancillary Facilities. Additional facilities and water area should be allocated for anchorage or moorage of ships awaiting repair service and for tugboats and fireboats. These facilities and areas may not be required within the shipyard limits if they are available nearby in the harbor.

f. Land Needs. Land area should be allocated to shipyard use in sufficient quantity to provide for rail or highway access, including onsite storage of vehicles and goods required for shipyard operations. Shop and office buildings, storage areas, and laydown spaces should be arranged to provide the most efficient flow of work and personnel within the facility consistent with the available space and mission of the shipyard.

Figure 37 is an example of the space allocation and arrangement of a sample shipyard.

9. EXAMPLES OF HARBOR LAYOUTS. See Figures 38 to 40.

10. METRIC EQUIVALENCE CHART. The following metric equivalents are approximate and were developed in accordance with ASTM E-621. These units are listed in the sequence in which they appear in the text of Section 3. Conversions are approximate.

1,000 feet	=	304.8 meters
10 knots	=	5.1 meters/second
3 knots	=	1.5 meters/second
15 knots	=	7.7 meters/second
3,000 feet	=	914.4 meters
1,200 feet	=	365.8 meters
2,000 feet	=	609.6 meters
4,000 feet	=	1,219.2 meters
7,000 feet	=	2,133.6 meters
10,000 feet	=	3,048 meters
500 feet	=	152.4 meters
700 feet	=	213.4 meters
5 knots	=	2.6 meters/second
3,500 feet	=	1,066.8 meters
2 feet	=	61 centimeters
4 feet	=	1.2 meters
33 feet	=	10.1 meters
18 feet	=	5.5 meters
30 feet	=	9.1 meters
50 feet	=	15.2 meters

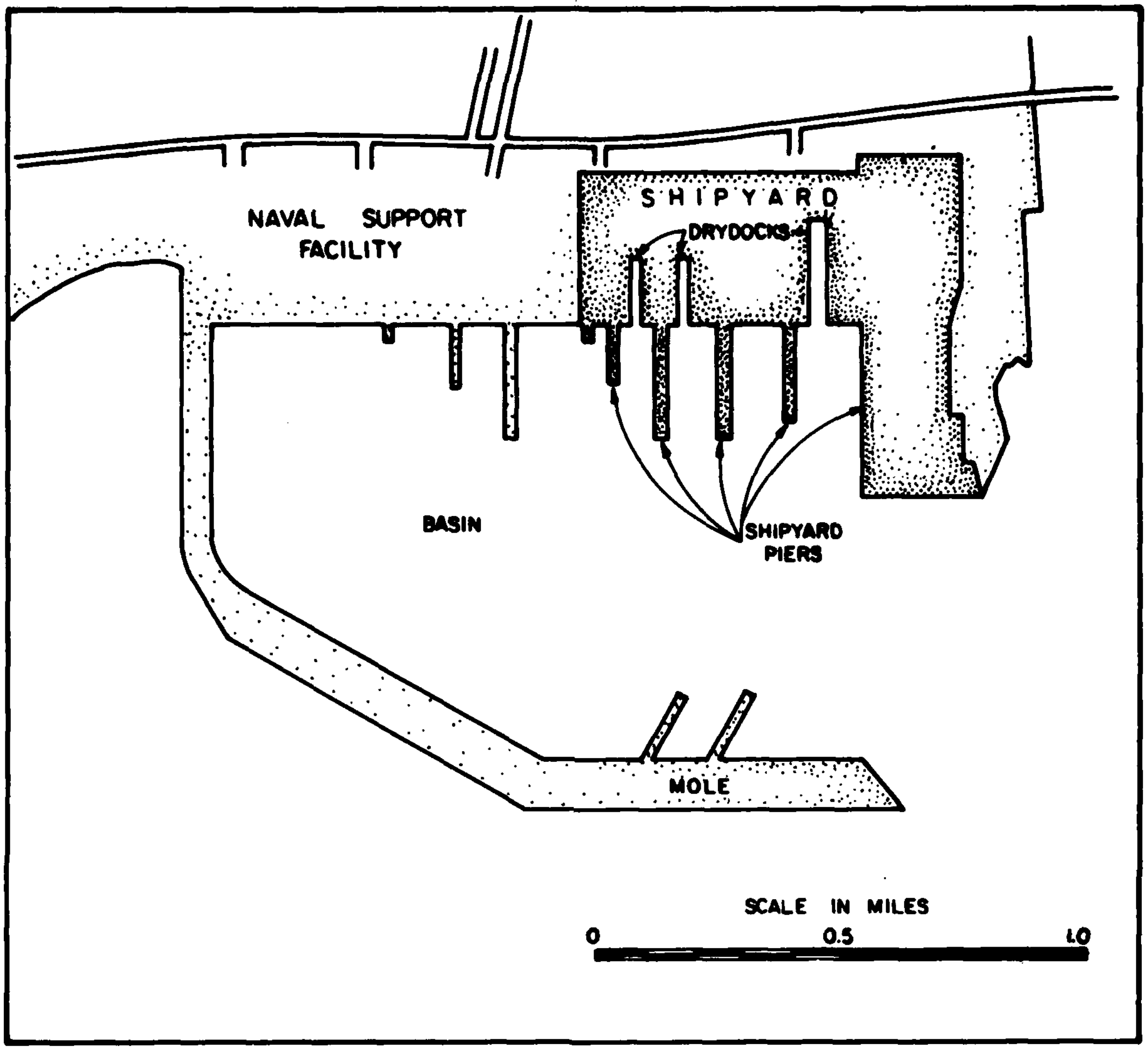


FIGURE 37
Sample Shipyard Layout

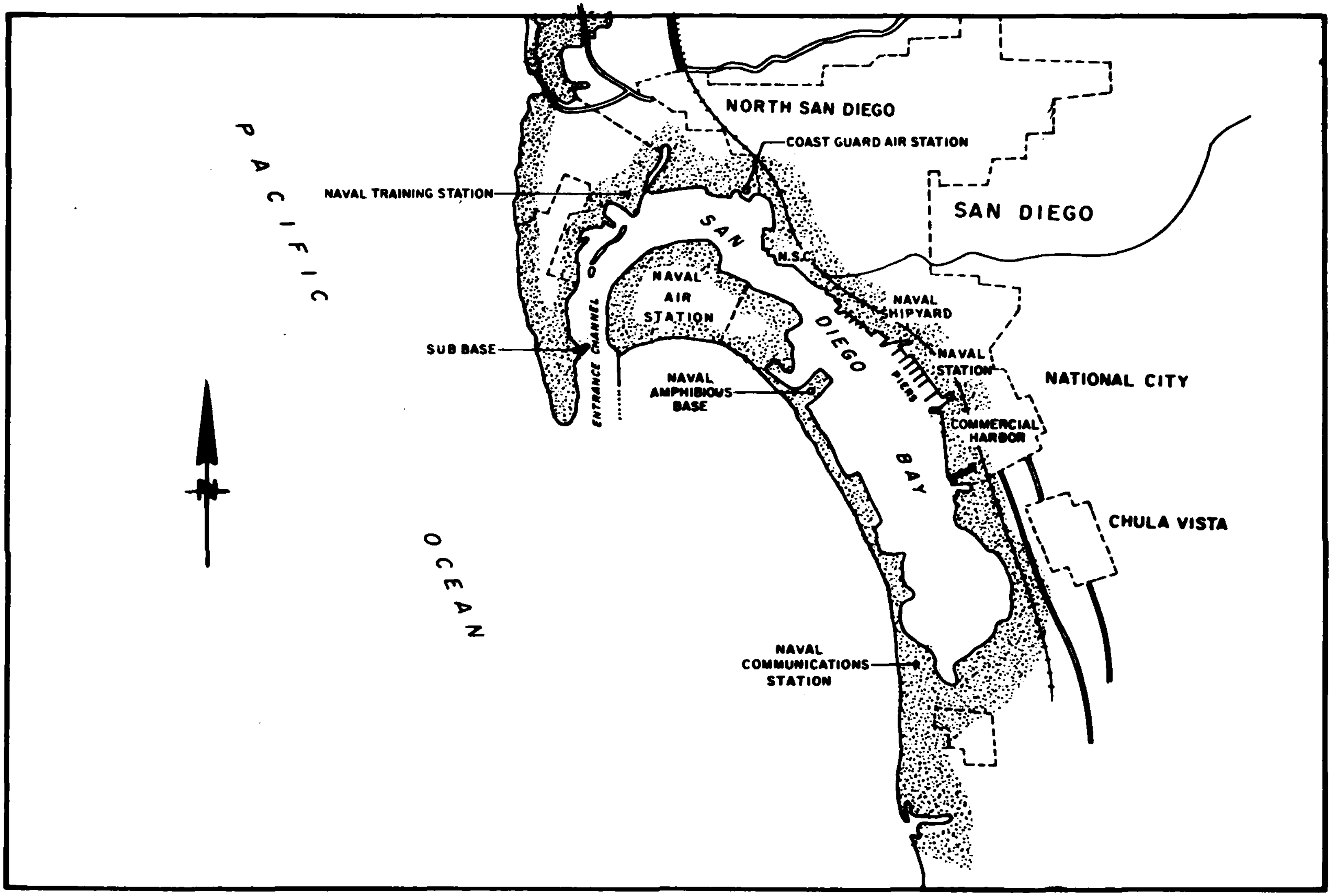


FIGURE 38
Typical Harbor Layout (San Diego Bay)

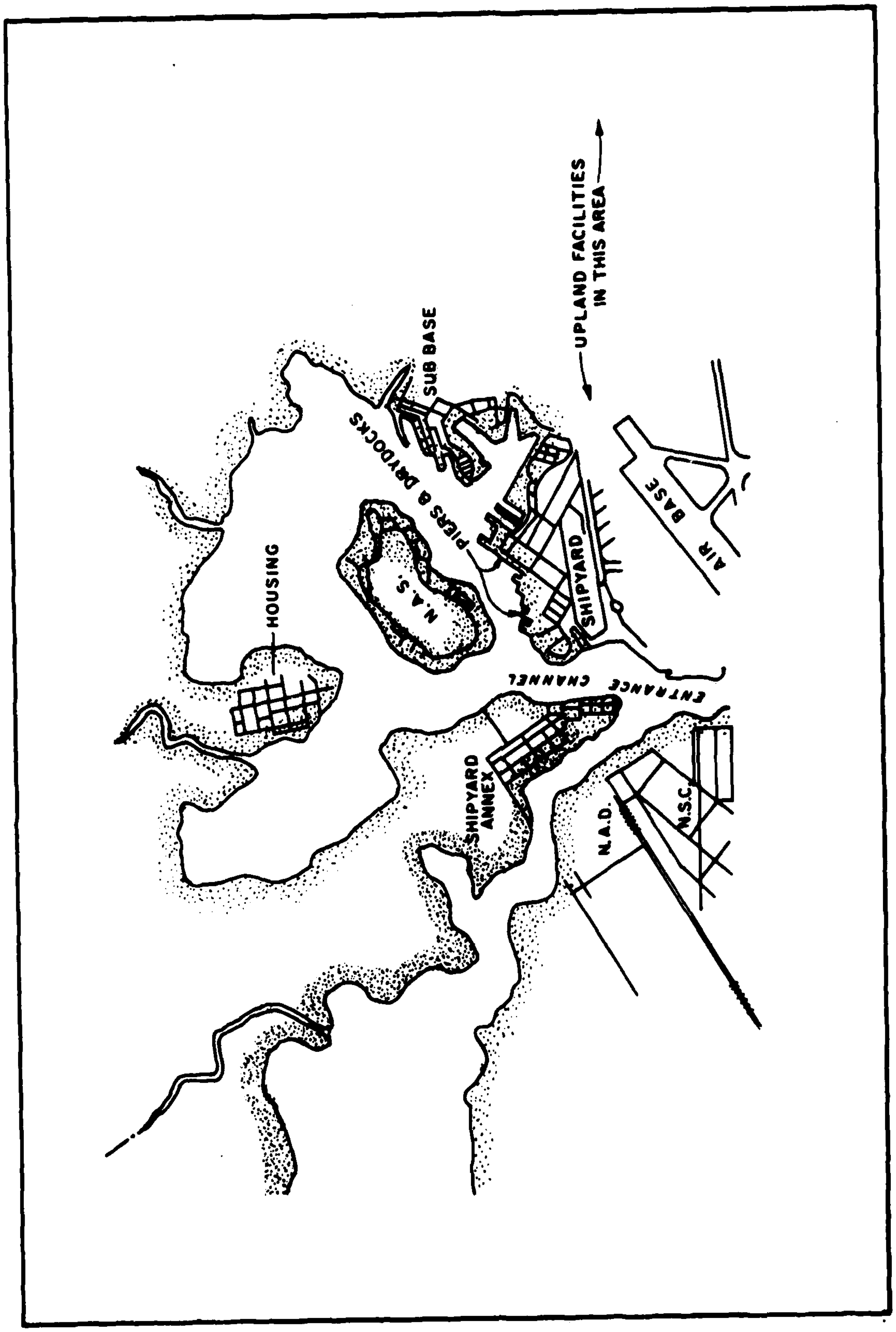


FIGURE 39
Typical Harbor Layout (Pearl Harbor)

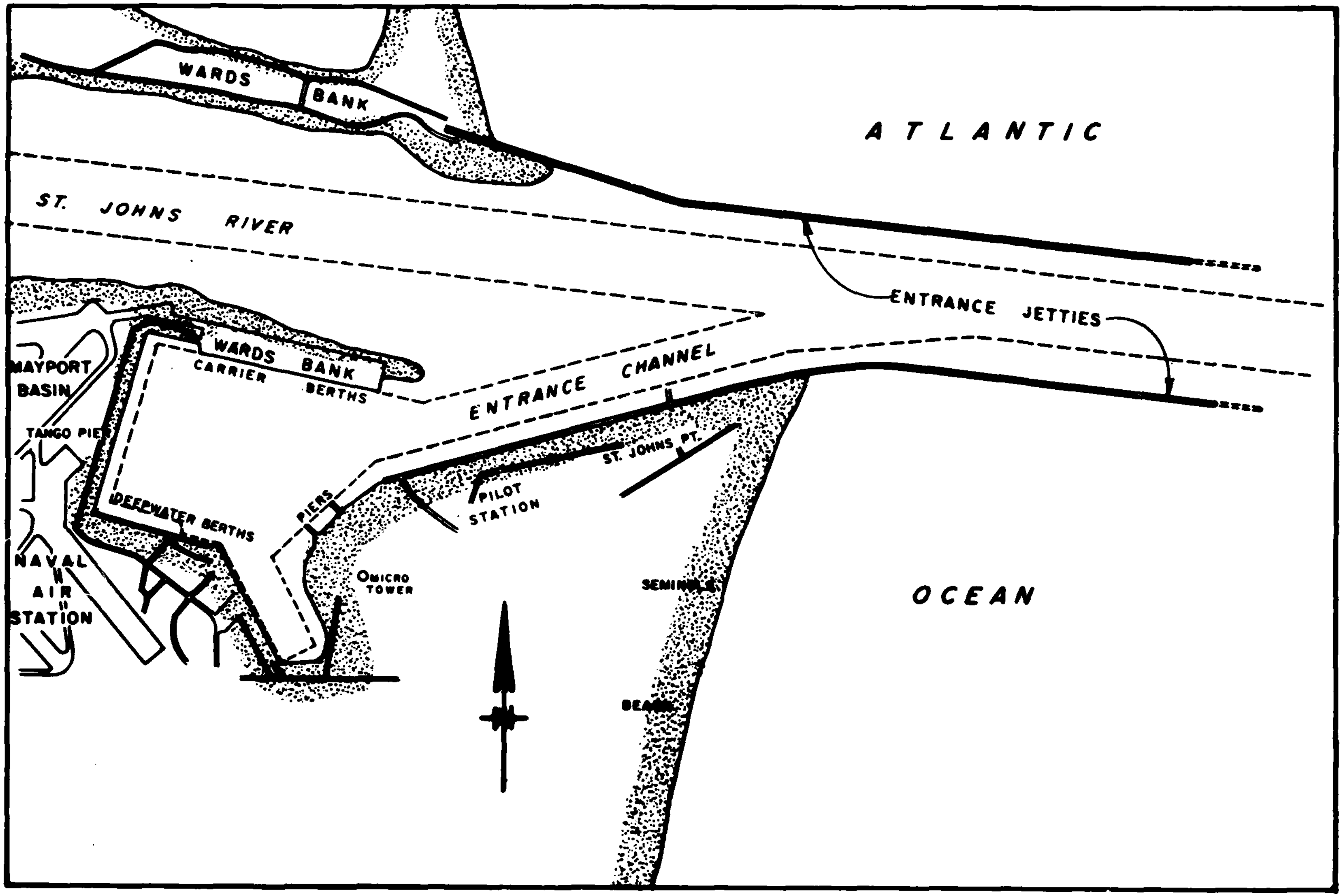


FIGURE 40
Typical Harbor Layout (Mayport Naval Station Basin)

Section 4. AIDS TO NAVIGATION

1. JURISDICTION. Where aids to navigation (such as lights, daybeacons, or buoys) are required, consult the District Office of the U.S. Coast Guard or the Commandant, U.S. Coast Guard, where no district office has jurisdiction. This organization will advise as to requirements for aids to navigation. The aids which conform to Coast Guard specifications may be purchased from the Coast Guard. Structures for supporting the aids (towers for lights or daybeacons and moorings for buoys) shall be provided by or under the cognizance of the Naval Facilities Engineering Command. The U.S. Coast Guard has specific jurisdiction over all aids to navigation in the continental United States and in all outlying territories and possessions. (Refer to Code of Federal Regulations, Title 33, for information relating to establishing aids to navigation.) In foreign countries, the regulations of local agencies (where such agencies exist) govern in lieu of the U.S. Coast Guard, but the Coast Guard will assist, when requested, in establishing aids to navigation, even in foreign countries.

2. TYPES OF AIDS. The following general data on aids to navigation are given to assist in preliminary layouts and as a basis to discuss requirements with the regulating agency. Aids to navigation include, but are not limited to, lighthouses (light stations), range lights, directional lights, minor lights, lighted and unlighted buoys, daybeacons, and fog signals. Other types of aids to navigation (not under the primary cognizance of the Naval Facilities Engineering Command) include lightships, radio beacons, radar beacons, and loran stations. Several types of navigational aids are illustrated in Figures 41 through 45.

a. Lighted Aids. Placing of lights is a function of local navigation requirements and topography. General rules are not applicable. Height of the lantern and type and candlepower of illuminant shall be specified. For daytime use, light structures shall be distinctively marked or painted in order to provide easy identification.

(1) Primary Seacoast Lights. These lights, which may be attended or automatic, are established on seacoasts, bays, sounds, and lakes for the purpose of marking landfalls and coastwise passages from headland to headland, and in harbors where powerful candlepower is necessary. The light source is designed to obtain the maximum geographic range.

(2) Secondary Lights. These lights, which also may be attended or automatic, are established on seacoasts where the needs for high candlepower and long range are less necessary, and on large inland waterways as intermediate aids in harbor channels and in other inshore channels where the requirements of navigation indicate that the range and candlepower of this class are necessary.

(3) Range Lights. These are pairs of lights located to form a range in line with the center of a channel or entrance to a harbor. The rear light is higher than the front light and a considerable distance in

back of it. The length of the range and width of the channel govern the height and distance of separation necessary between the lights. Range-light structures shall be equipped with daymarks for ordinary daytime use. Ranges may be used either ahead or over the stern.

(4) Directional Lights. A directional light is a single light which will project a beam of high intensity, separate color, or other special characteristic, in a given direction. It has limited use in those cases where a two-light range may not be practicable or necessary, and for other special applications. The directional light is essentially a narrow-sector light with or without adjacent sectors which give information as to the direction of and relative displacement from the narrow sector.

(5) Minor Lights. These are lights of relatively low candlepower usually established in harbors, along channels, along rivers, and in isolated locations. They are generally unattended and unwatched and should operate automatically. Depending upon circumstances, these lights may be displayed from towers, skeleton structures, or from a group of piles. They shall be colored to distinguish them from the surrounding background and from adjacent structures.

(6) Lighted Buoys. These are floating aids showing from the upper of their structures an automatically operated, low-candlepower light. Colors and characteristics vary. Lighted buoys are established for the purpose of definitely identifying spots. These include the entrance and side limits of natural and dredged channels, centers of fairways, obstructions and wrecks, isolated natural dangers in offshore or restricted waters, and for special purposes such as quarantine or general anchorages. These lights are powered by batteries.

b. Unlighted Aids.

(1) Unlighted Buoys. These are floating aids of varying size, shape, and color. They serve the same general purposes as lighted buoys. They are used in areas of lesser importance or as intermediate aids to supplement lighted buoys in the more important areas.

(2) Daybeacons. Although all aids, whether lighted or unlighted, serve as a daymark to the mariner, daybeacons are specifically designed as unlighted structures used to mark isolated dangers, channels, edges, or alinement.

c. Sound Fog Signals. Sound fog signals are sound-producing devices operated mechanically or by the action of the sea, consisting of horns, sirens, diaphones, bells, gongs, and whistles. They are installed on shore structures and on buoys.

(1) Operation. Most fog signals on structures are attended. Fog signals on a few minor shore structures or on buoys shall be automatically operated. Other signals on buoys shall be operated by action of the sea.

(2) Purpose. Fog signals are intended to warn of danger and provide the mariner with the best practicable means of determining his

position. This is in relation to the sound signal station at such times as the station, or any light that it might display, is obscured from view by fog, haze, smoke, or generally poor visibility.

(3) Range. To be effective, fog signals must be capable of a useful range, and they must be of such characteristic duration as to permit their direction to be judged with reasonable accuracy by ear. It must be remembered that due to the uncertainty of passage of sound through the atmosphere, the range of sound signals cannot be depended upon or specifically fixed. Major fog signals shall have a minimum range of 1-1/2 miles.

3. LIGHTS. Due to the increase in shore illumination along navigable waters, the usefulness of fixed white lights is limited to areas where the usable range is short or where the natural background includes few other lights.

a. Length of Period. The period of a flashing or occulting light is the time required to go through a full set of changes. The limiting basis for the period of light characteristics is 60 seconds, since it is considered that the mariner cannot always safely watch the light to the exclusion of everything else for a longer period. Light characteristics which are so similar as to require careful timing in order to differentiate between them should not be established in close proximity to one another.

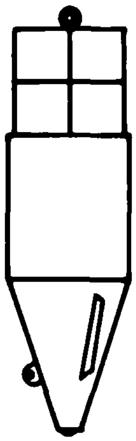
b. Colors. White, red, and green are used for navigational lights. Other colors are not used.

(1) Means of Obtaining Color. The light source in all illuminating apparatus is white. Color is produced by the addition of colored-glass shades or screens.

(2) Alternating Colors. In certain instances, light characteristics consist of alternations of colors, with either two or three colors being used in combination. Where an alternating white and red or white and green light is desired, the candlepower of the colors shall be equalized by selection of the lens panels.

c. Visibility. The distances at which lights may be seen in clear weather are computed for a height of the observer's eye of 15 feet above sea level. Table 21 gives the approximate geographical range of visibility for objects of varying elevations which may be seen by an observer whose eye is at sea level. To determine the distance of visibility for an observer whose eye is at an elevation other than sea level, add to the distance of visibility (determined from Table 21) the distance of visibility from Table 21 which corresponds to the elevation of the observer's eye above sea level.

d. Suppliers. Lights built to Coast Guard specifications may be purchased from the U.S. Coast Guard or from a manufacturer.



1952 TYPE STANDARD

FUNCTION

THE 2 CR BUOY IS DESIGNED AND CONSTRUCTED FOR EXPOSED OR SEMIEXPOSED LOCATIONS WHERE AN UNLIGHTED BUOY IS REQUIRED.

PHYSICAL CHARACTERISTICS

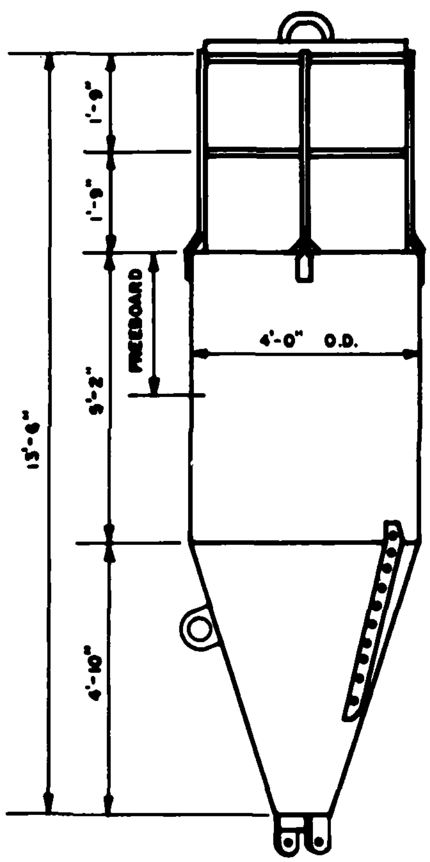
BUOY WEIGHT	2,700 LB
BUOY DRAFT (NO MOORING)	6 FT - 11 IN
FREEBOARD (NO MOORING)	3 FT - 11 IN
MINIMUM FREEBOARD	1 FT - 0 IN
POUNDS PER INCH OF IMMERSION	67

RELATED EQUIPMENT

MOORING CHAIN SIZE	7/8 IN
SINKER SIZE	4,000 LB

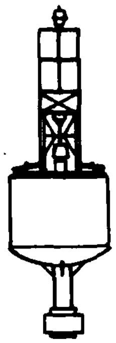
OPERATIONAL CHARACTERISTICS

NOMINAL VISUAL RANGE OF DAYMARK	2.8 NMI
RADAR RANGE	2.5 NMI
MAXIMUM CURRENT	6 K
MINIMUM MOORING DEPTH	15 FT
MAXIMUM MOORING DEPTH	200 FT



DIMENSIONS OF THE 2 CR

FIGURE 41
The 2 CR Buoy



1962 TYPE STANDARD

FUNCTION

THE 8x26 LBR BUOY IS DESIGNED AND CONSTRUCTED FOR EXPOSED OR SEMIEXPOSED LOCATIONS. THIS BUOY CONFIGURATION IS USED WITH A 225-LB BELL, WAVE-ACTUATED SOUND SIGNAL. THE BASIC BUOY IS THE SAME AS THE 8x26 LR.

PHYSICAL CHARACTERISTICS

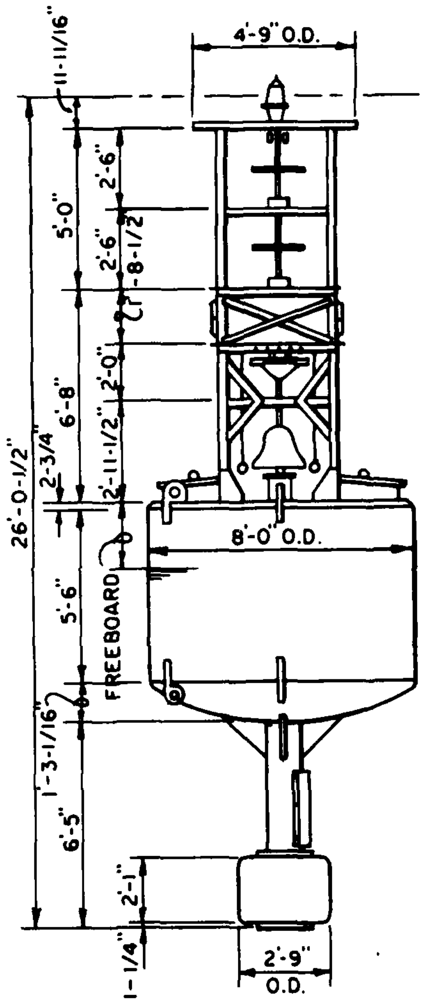
BUOY WEIGHT	11,917 LB
BUOY DRAFT (NO MOORING)	10 FT-3 IN
FOCAL HEIGHT OF LIGHT (NO MOORING)	15 FT.-8 IN
FREEBOARD (NO MOORING)	3 FT-1 IN
MINIMUM FREEBOARD	1 FT-3 IN
POUNDS PER INCH OF IMMERSION	270

RELATED EQUIPMENT

POWER UNITS (MAXIMUM NUMBER AND SIZE)	2-B30
SOUND EQUIPMENT	225-LB BELL
BRIDLE SIZE (CHAIN DIAMETER AND LENGTH)	1-1/4 IN x 15 FT
MOORING CHAIN SIZE	1-1/4 IN
SINKER SIZE	8,500 LB

OPERATIONAL CHARACTERISTICS

NOMINAL VISUAL RANGE OF DAYMARK	3.2 NMI
RADAR RANGE	3.7 NMI
MAXIMUM CURRENT	4 K
MAXIMUM MOORING DEPTH	25 FT
MAXIMUM MOORING DEPTH (B10)	220 FT
(B30)	190 FT



DIMENSIONS OF 8x26 LBR.

FIGURE 42
The 8 x 26 LBR Buoy

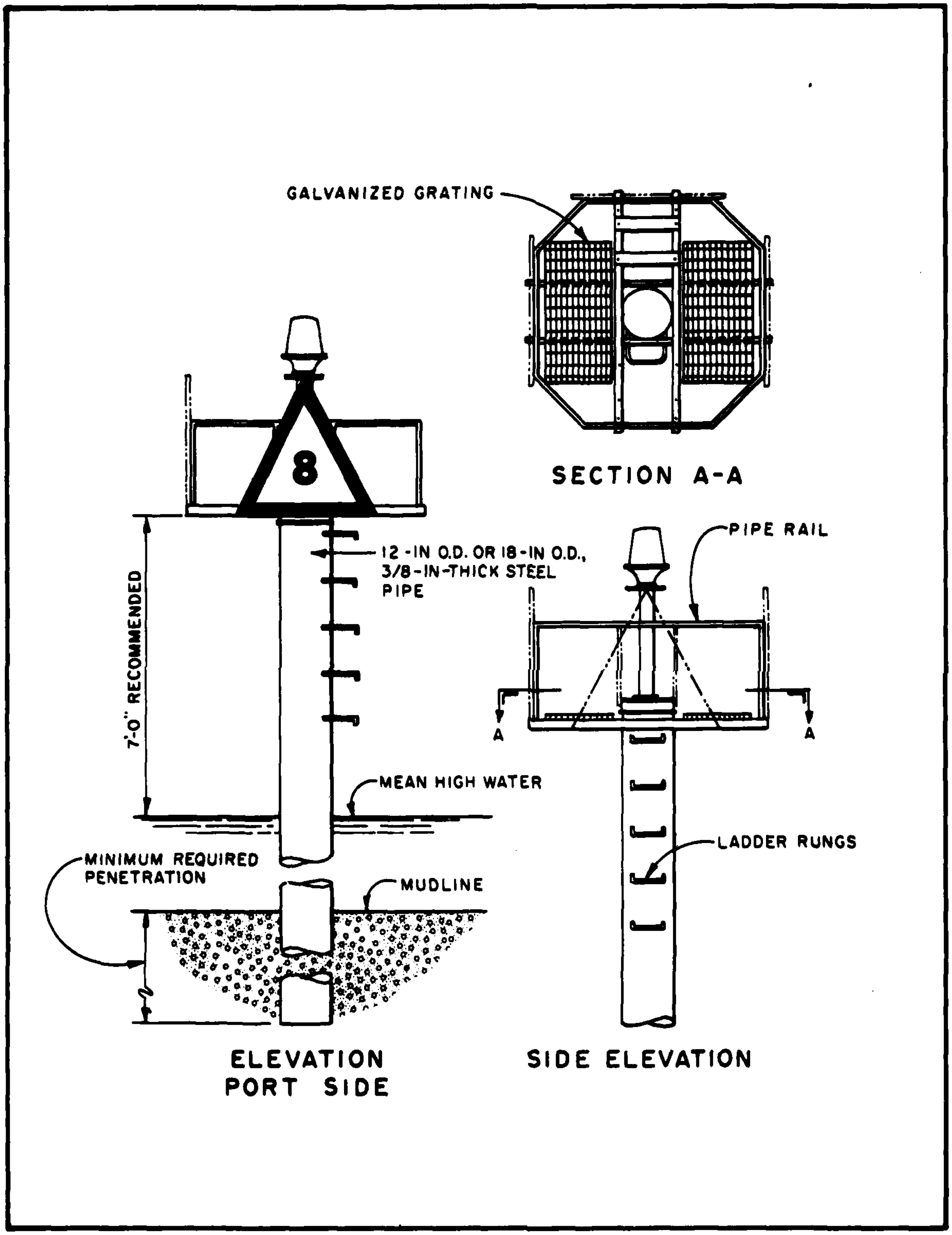


FIGURE 43
Single Pile Steel Beacon Structure (Lighted)

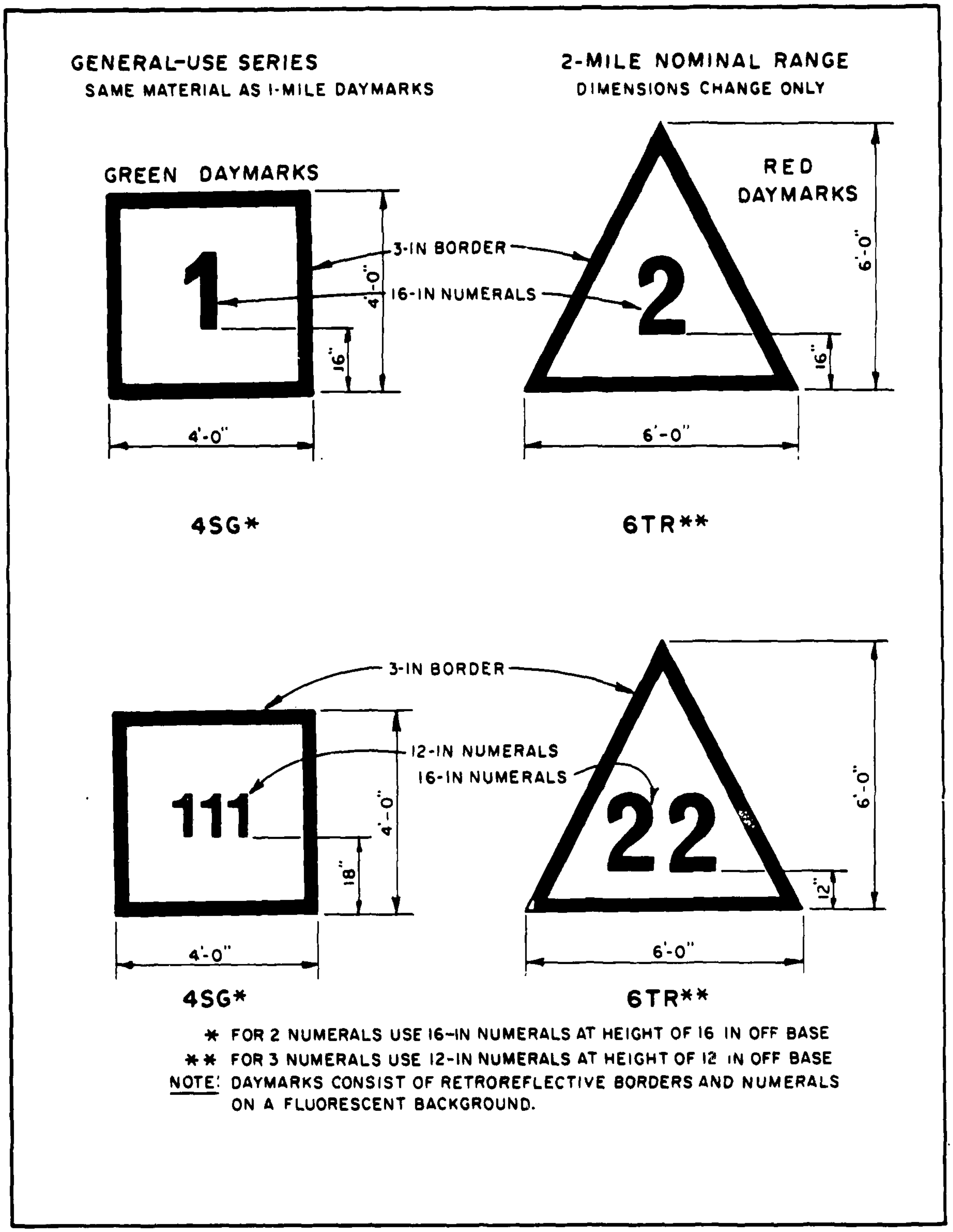


FIGURE 44
Lateral Daymarks

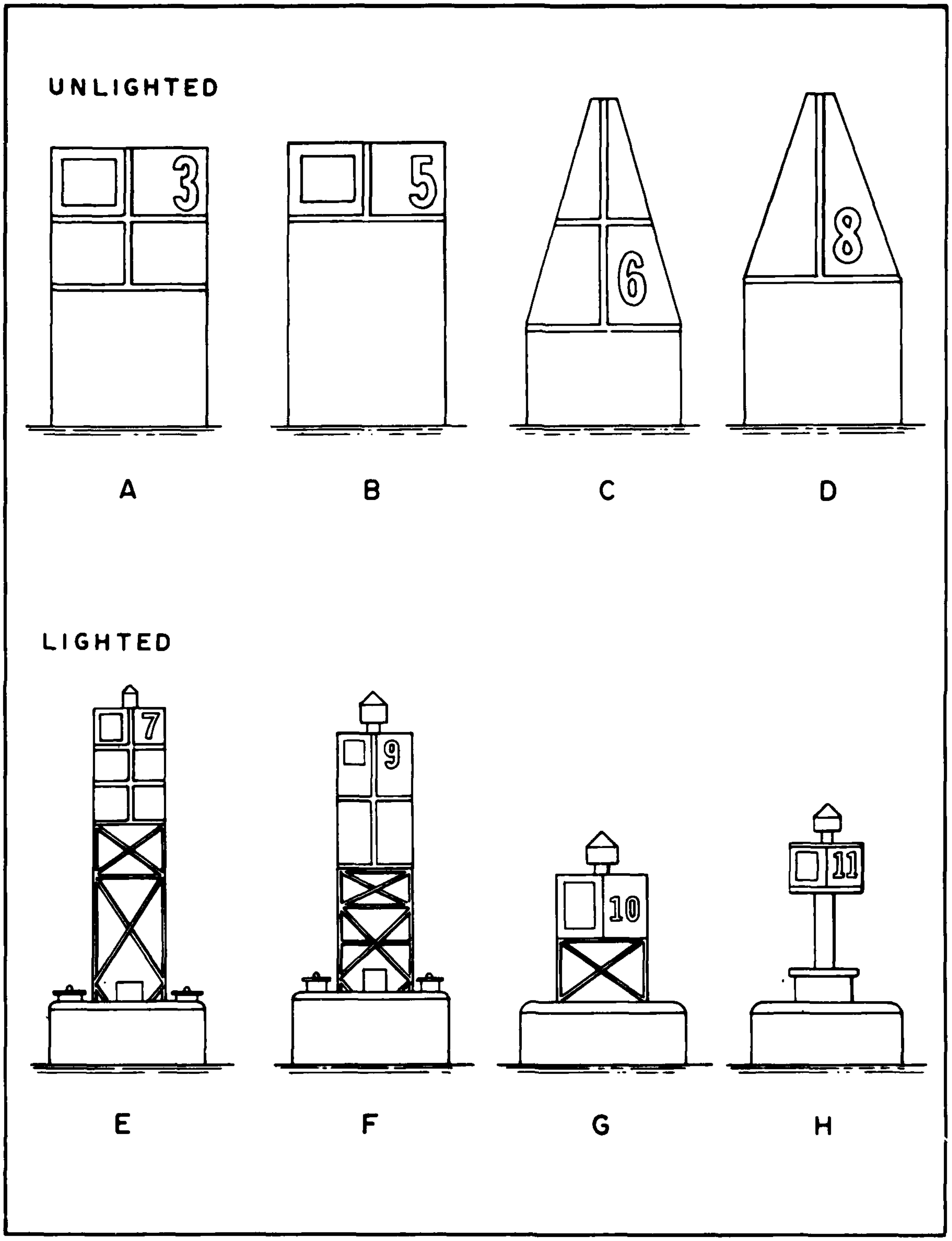


FIGURE 45
General-Use Series Buoys, Radar Reflector Type

TABLE 21
Distances of Visibility for Objects
of Various Elevations Above Sea Level

Elevation (ft)	Distance (nmi)	Elevation (ft)	Distance (nmi)	Elevation (ft)	Distance (nmi)
5	2.5	70	9.6	250	18.2
10	3.6	75	9.9	300	19.9
15	4.4	80	10.3	350	21.5
20	5.1	85	10.6	400	22.9
25	5.7	90	10.9	450	24.3
30	6.3	95	11.2	500	25.6
35	6.8	100	11.5	550	26.8
40	7.2	110	12.0	600	28.0
45	7.7	120	12.6	650	29.1
50	8.1	130	13.1	700	30.3
55	8.5	140	13.6	800	32.4
60	8.9	150	14.1	900	34.4
65	9.2	200	16.2	1000	36.2

4. BUOYS. Buoys are used for lateral identification for channels in navigable waters. Demarcation of the channel is accomplished by arranging the colors, shapes, numbers, and light characteristics of the buoys. The standard coding system of the U.S. Coast Guard should be followed, where possible, and shall be obtained from that organization. Special buoys, having no lateral significance, *should be used for* marking anchorages, nets, and dredging and other special-purpose areas. For characteristics of buoys, consult the U.S. Coast Guard.

5. DAYBEACONS. Daybeacons shall be constructed and painted in order to be distinct and conspicuous. Only white, green, or red color shall be used, either separately or in combination. Where a number of daybeacons are to be used within a limited area, use different types of construction to assist in distinguishing among them. Daybeacons should be reflectorized for night use.

6. FOG SIGNALS. Fog signals at stations where a continuous watch is maintained shall be designed to be sounded both when the visibility decreases to 5 miles and when the fog whistle of a passing vessel is heard. Fog signals at locations where no watch is maintained shall be designed to operate continuously or automatically. Fog signals on buoys generally should be operated by the motion of the sea and should operate continuously.

a. Sound Intervals. Blasts shall be a minimum 2 seconds in length, occurring at intervals not exceeding 60 seconds; preferable interval length is 15 seconds.

b. Suppliers. Fog signals built to Coast Guard specifications may be purchased from the U.S. Coast Guard or from a manufacturer.

7. RANGES. Height, distance apart, size of daymark, and color marking are dependent on local conditions, and general rules are not applicable. There are no rules as to shape of the daymark, except that it be the most distinctive possible shape in the range system.

8. DESIGN OF SUPPORT STRUCTURES. Dolphins, towers, and similar supports for lights, daybeacons, and similar aids shall be designed in accordance with requirements for the same or similar structures established elsewhere in this manual.

9. MOORINGS. Moorings for buoys shall be designed in accordance with the requirements of DM-26.5. Where standard mooring designs are not applicable, wind and current forces on buoys must be analyzed. Wind forces on cylindrical surfaces may be approximated according to DM-2.1.

10. BUOY SYSTEMS. The U.S. and most Western-Hemisphere countries use a buoy system based on green daymarks/black buoys for port hand and red daymarks/red buoys for starboard hand when returning from sea. Many Eastern-Hemisphere countries use green for starboard and red for port hand. The system that is used in the local area is an important consideration when designing a new aid system.

11. METRIC EQUIVALENCE CHART. The following metric equivalents are approximate and were developed in accordance with ASTM E-621. These units are listed in the sequence in which they appear in the text of Section 4. Conversions are approximate.

1-1/2 miles = 2.4 kilometers
15 feet = 4.6 meters
5 miles = 8.0 kilometers

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DM-2.1	Structural Engineering General Requirements
DM-23.2	Navigational and Traffic Aids
DM-25.1	Piers and Wharves
DM-25.2	Dockside Utilities for Ship Service
DM-25.3	Cargo Handling Facilities
DM-25.5	Ferry Terminal and Small Craft Berthing Facilities
DM-25.6	General Criteria for Waterfront Construction
DM-26.2	Coastal Protection
DM-26.5	Fleet Moorings
DM-26.6	Mooring Design Physical and Empirical Data
DM-38	Weight Handling Equipment and Service Craft

GLOSSARY

<u>Alluvium</u>. Soil (sand, mud, or similar detrital material) deposited by streams, or the deposits so formed.

<u>Antinode</u>. That part of a standing wave wherein the vertical motion is greatest and the horizontal velocities are least.

<u>Basin</u>. A naturally or artificially enclosed or nearly enclosed harbor area for small craft.

<u>Bay</u>. A recess in the shore or an inlet of a sea between two capes or headlands, not as large as a gulf but larger than a cove.

<u>Beam</u>. Maximum width of a vessel hull.

<u>Berth</u>. A place where a boat may be secured to a fixed or floating structure and left unattended.

<u>Biofouling</u>. (See Fouling.)

<u>Breakwater</u>. A structure protecting a shore area, harbor, anchorage, or basin from waves.

<u>Bulkhead</u>. A structure, designed to retain earth, which consists of a vertical wall sometimes supplemented by an anchor system.

<u>Bulkhead Lines</u>. Lines which establish limits outside of which continuous solid-fill construction is not permitted.

<u>Caisson</u>. A watertight box used as a closure for graving-dock entrances.

<u>Camel</u>. A float placed between vessel and dock, or between vessels, designed to distribute wind and current forces acting on the vessel.

<u>Constituent</u>. (See Tidal Constituent.)

<u>Controlling Depth</u>. The least depth in the navigable parts of a waterway, governing the maximum draft of vessels that can enter.

<u>Current</u>. A flow of water.

<u>Cyclone</u>. A closed atmospheric circulation containing lower pressure than its surroundings, having a sense of rotation the same as that of the earth's rotation: clockwise in the Southern Hemisphere and counterclockwise in the Northern Hemisphere.

<u>Datum</u>. The horizontal plane to which soundings, ground elevations, or water-surface elevations are referred.

<u>Diurnal</u>. Having a period or cycle of approximately one tidal day.

Diurnal Tide. A tide with one high water and one low water in a tidal day.

Dock. A pier or wharf used for berthing vessels and for transfer of cargo or passengers.

Dolphin. A structure, usually consisting of a cluster of piles, placed near piers, wharves, or similar structures, or alongshore, to guide vessels into their moorings or to fend vessels away from structures, shoals, or the shore.

Draft. Depth of vessel hull below the waterline.

Drydock. A large floating or stationary (graving) dock in the form of a basin from which the water can be emptied; used for maintaining, repairing, and/or altering a ship below the waterline.

Dwt. Dead weight tons.

Ebb Tide. The period of tide between high water and the succeeding low water; a falling tide.

Embayment. An indentation in the shoreline forming an open bay.

Environmental Impact Statement. A report on the expected effects or influence any development will have on its environment.

Erosion. The wearing away of land by the action of natural forces.

Estuary. (1) The part of a river that is affected by tides. (2) The region near a river mouth in which the fresh water of the river mixes with the salt water of the sea.

Fender. A device or framed system placed against the edge of a dock to take the impact from berthing or berthed vessels.

Fetch Length. The horizontal distance (in the direction of the wind) over which a wind generates seas or creates a wind setup.

Flood Tide. The period of tide between low water and the succeeding high water; a rising tide.

Fouling. The attachment and growth of marine plants and animals on surfaces of operational importance to man.

Freeboard. (1) The additional height of a structure above design high water level to prevent overflow. (2) At a given time, the vertical distance between the water level and the top of the structure. (3) On a ship, the distance from the waterline to main deck or gunwale.

Froude Number. The dimensionless ratio of the inertial force to the force of gravity for a given fluid flow.

Graving Drydock. (See Drydock.)

Harbor. In general a sheltered arm of the sea, bounded by natural features, manmade structures, or a combination of both, in which ships may seek refuge, transfer cargo, and/or undergo repair.

Headland. A high, steep-faced promontory extending into the sea.

Heave. The rhythmic vertical displacements of an entire craft under wave excitation.

Hurricane. An intense tropical cyclone in which winds tend to spiral inward toward a core of low pressure, with maximum surface-wind velocities that equal or exceed 70 miles per hour for several minutes or longer at some points. "Tropical storm" is the term applied if maximum winds are between 55 and 70 miles per hour.

Inlet. A short, narrow waterway connecting a bay, lagoon, or similar body of water with a large parent body of water.

Jetty. On open seacoasts, a structure extending into a body of water, designed to prevent shoaling of a channel by littoral materials and to direct and confine the stream or tidal flow. At the mouth of a river or tidal inlet, jetties are built to help maintain and stabilize a channel.

Keel. The principal structural member of a ship, running fore and aft on the centerline, extending from bow to stern and forming the backbone of the vessel to which the frames are attached.

Lee. (1) Shelter, or the part or side sheltered or turned away from the wind or waves. (2) (Chiefly nautical) The quarter or region toward which the wind blows.

Lighter. A small vessel used for transfer of cargo from ship to dock or vice versa, in shallow-water harbors.

List. An inclination of a vessel to one side.

Littoral Drift. The sedimentary material moved in the littoral zone under the influence of waves and currents.

Lock. A section of a waterway, closed off with gates, in which a vessel may be raised or lowered by the raising or lowering of the water level in the section.

Marigram. A graphic record of the rise and fall of the tide.

Mean Higher High Water (MHHW). The average height of the higher high waters over a 19-year period. For shorter periods of observation, corrections are applied to eliminate known variations and reduce the result to the equivalent of a mean 19-year value.

Mean High Water (MHW). The average height of the high waters over a 19-year period. For shorter periods of observations, corrections are applied to eliminate known variations and reduce the results to the equivalent of a mean 19-year value.

Mean Lower Low Water (MLLW). The average height of the lower low waters over a 19-year period. For shorter periods of observations, corrections are applied to eliminate known variations and reduce the results to the equivalent of a mean 19-year value. Frequently abbreviated to lower low water.

Mean Low Water (MLW). The average height of the low waters over a 19-year period. For shorter periods of observations, corrections are applied to eliminate known variations and reduce the results to the equivalent of a mean 19-year value.

Mean Low Water Springs (MLWS). The average height of low waters occurring at the time of the spring tides. It is usually derived by taking a plane depressed below the half-tide level by an amount equal to one-half the spring range of tide, necessary corrections being applied to reduce the result to a mean value. This plane is used to a considerable extent for hydrographic work outside of the United States and is the plane of reference for the Pacific approaches to the Panama Canal.

Mean Sea Level (MSL). The average height of the surface of the sea for all stages of the tide over a 19-year period, usually determined from hourly height readings. Not necessarily equal to mean tide level.

Mean Tide Level. A plane midway between mean high water and mean low water. Not necessarily equal to mean sea level. Also called half-tide level.

Mixed Tide. A type of tide in which the presence of a diurnal wave is conspicuous by a large inequality in either the high- or low-water heights, with two high waters and two low waters usually occurring each tidal day. In strictness, all tides are mixed, but the name is usually applied without definite limits to the tide intermediate to those predominantly semidiurnal and those predominantly diurnal.

Mole. A massive land-connected, solid-fill structure of earth (generally revetted), masonry, or large stone. It may serve as a breakwater or pier.

National Geodetic Vertical Datum (NGVD). The datum of the United States geodetic level net. Mean Sea Level varies slightly from this datum from place to place along the shores of the Nation.

Node. That part of a standing wave wherein the vertical motion is least and the horizontal velocities are greatest.

Outriggers. Any projecting frame extending laterally beyond the main structure of a vessel to stabilize the structure or to support an extending part.

Pier. A dock that is built from the shore out into the harbor and used for berthing and mooring vessels.

Pierhead Lines. Lines which establish the outboard limit of open-pier construction.

Pitch. The rotational oscillations of a craft about its transverse axis under wave excitation.

Port. A place where vessels may discharge or receive cargo; may be the entire harbor, including its approaches and anchorages, or may be the commercial part of a harbor where the quays, wharves, facilities for transfer of cargo, docks, and repair shops are situated.

Quay. A stretch of paved bank, or a solid artifical landing place parallel to the navigable waterway, usually with a vertical or nearly vertical face, for use in loading and unloading vessels.

Quayage. Room on or for quays.

Roadsteads. (Nautical) A sheltered area of water near the shore, where vessels may anchor in relative safety. Also "road."

Rode. Anchor cable.

Roll. The rotational oscillations of a craft about its longitudinal axis under wave excitation.

Seawall. A structure separating land and water areas, primarily designed to prevent erosion and other damage due to wave action.

Seiche. A standing-wave oscillation of an enclosed water body that continues after the cessation of the originating force.

Semidiurnal Tide. A tide with two high and two low waters in a tidal day, with comparatively little diurnal inequality.

Shoal. (1) (Verb) (a) To become shallow gradually. (b) To cause to become shallow. (c) To proceed from a greater to a lesser depth of water. (2) (Noun) A rise of the sea bottom due to an accumulation of sand or other sediments.

Silt. Generally, refers to fine-grained soils having particle diameters between 0.002 and 0.05 millimeter.

Slip. A space between two piers for berthing a vessel.

Squat. The vertical downward displacement of a craft under power with respect to its position in the water when not underway.

Standing Wave. A type of wave in which the surface of the water oscillates vertically between fixed points, called nodes, without progression.

Stillwater Level. The elevation that the surface of the water would assume if all wave action were absent.

Storm Surge. A rise above normal water level on the open coast due to the action of wind on the water surface. (See Wind Setup.)

Surge. The rhythmic longitudinal displacements of an entire craft under wave excitation.

Sway. The rhythmic transverse displacements of an entire craft under wave excitation.

Swell. Wind-generated waves that have traveled out of their generating area. Swell characteristically exhibits a more regular and longer period, and has flatter crests, than waves within their fetch.

Tidal Constituent. Simple harmonic waves associated with the attractive forces of the moon and sun.

Tidal Day. The time of the rotation of the earth with respect to the moon, or the interval between two successive upper transits of the moon over the meridian of a place; approximately 24.84 solar hours (24 hours and 50 minutes) or 1.035 times the mean solar day.

Tidal Period. The interval of time between two consecutive like phases of the tide.

Tidal Range. The difference in height between consecutive high and low (or higher high and lower low) waters.

Tide. The periodic rising and falling of the water that results from gravitational attraction of the moon and sun and other astronomical bodies acting upon the rotating earth.

Trim. The difference between the draft at the bow and at the stern of a vessel.

Trochoidal Wave. A theoretical, progressive oscillatory wave first proposed by Gerstner in 1802 to describe the surface profile and particle orbits of finite amplitude, nonsinusoidal waves.

Tsunami. A long-period wave caused by an underwater disturbance such as a volcanic eruption or an earthquake. Commonly miscalled "tidal wave."

Waterline. A junction of land and sea. This line migrates, changing with the tide or other fluctuations in the water level.

Wave. A ridge, deformation, or undulation of the surface of a liquid.

Wave Height. The vertical distance between a crest and the preceding trough.

Wavelength. The horizontal distance between similar points on two successive waves measured perpendicularly to the crest.

Wave Period. The time for a wave crest to traverse a distance equal to one wavelength. The time for two successive wave crests to pass a fixed point.

Wave Setup. Superelevation of the water surface over normal surge elevation due to onshore mass transport of the water by wave action alone.

Wharf. A dock that is oriented approximately parallel to shore, with more than one access connection with the shore, and used for berthing or mooring vessels.

Wind Setup. (1) The vertical rise in the stillwater level on the leeward side of a body of water caused by wind stresses on the surface of the water. (2) The difference in stillwater levels on the windward and the leeward sides of a body of water caused by wind stresses on the surface of the water. (3) Synonymous with "wind tide" and "storm surge." "Storm surge" is usually reserved for use on the ocean and large bodies of water. "Wind setup" is usually reserved for use on reservoirs and smaller bodies of water. (See Storm Surge.)

Yaw. The rotational oscillations of a craft about its vertical axis under wave excitation.

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